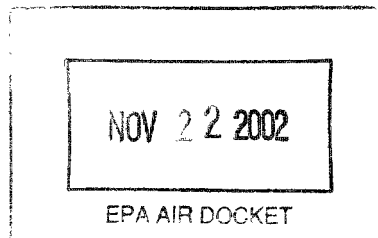


*Summary of  
Hazardous Air Pollutant Emissions  
from Selected Petroleum Refineries*

*November 1991*



*Prepared for:  
U.S. Environmental Protection Agency  
Office of Air Quality Planning and Standards  
Chemicals and Petroleum Branch  
Research Triangle Park, NC 27711*

**RADIAN**  
CORPORATION

SUMMARY OF HAZARDOUS AIR POLLUTANT EMISSIONS FROM SELECTED  
PETROLEUM REFINERIES

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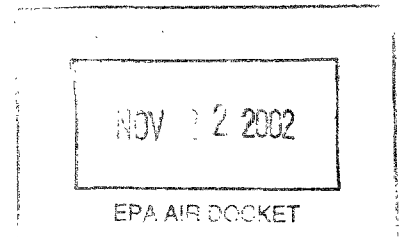
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## 1.0 INTRODUCTION

Title III of the 1990 Clean Air Act amendments (CAA) requires the U. S. Environmental Protection Agency (EPA) to develop emission standards for 190 listed hazardous air pollutants (HAP's). One of the initial activities the EPA must undertake in responding to Title III is to identify the source categories that warrant regulation. After creating a list of source categories, EPA must then establish priorities among them and develop regulations for these categories over a 10-year period.

Petroleum refining is among of potential source categories to be regulated under Section 112 of the Clean Air Act. Accordingly, for each subcategory of petroleum refinery HAP emissions, EPA must evaluate the baseline emission levels (including any existing controls), available control technologies, potential emissions reductions beyond baseline, and costs of control. Ultimately, EPA must decide which subcategories of petroleum refinery HAP emissions warrant regulation under Section 112.

### 1.1 PROJECT OBJECTIVES

The overall objective of this project was to estimate petroleum refinery emissions of the 190 HAP's listed in the CAA. The effort involved quantifying emissions from every refinery process unit for each of the following classifications: process vents, equipment leaks, storage tanks, transfer operations, and wastewater collection and treatment. The goal was to develop emission factors for 1) each HAP, 2) total HAP's, and 3) total volatile organic compounds (VOC). Furthermore, annual emissions of all HAP's were to be determined for each refinery process and for each individual refinery in the United States.

## 1.2 DATA COLLECTION AND ANALYSIS METHODOLOGY

The initial phase of the project involved collecting and assembling all currently available information for developing emission factors and emissions estimates. A search of the literature and available EPA databases was conducted for specific data on HAP's from refinery processes, as well as for the HAP content of refinery streams, (feedstocks, intermediates, products, and wastewater). The databases maintained by EPA's Office of Water were reviewed for pertinent information in estimating HAP emissions from wastewater, sludge, and other wastes produced in refinery processes. The EPA's Toxic Release Inventory System (TRIS) was reviewed for each U. S. refinery and tabulated by the specific and total HAP constituents emitted from the refining industry. In addition, annual emissions from each refinery and the number of refineries reporting an emission of each HAP were summarized from the TRIS database.

In the next phase, efforts focussed on data that would be available as a result of State/local agency air toxics initiatives. Specifically, it was known that the California air quality management districts were requiring data that would be potentially very useful to the project. Consequently, the specific information submitted by California refineries under California's Air Toxics "Hot Spots" Information and Assessment Act of 1987 (AB 2588) served as the primary source of information for the project. Compared to information collected in the initial screening activity discussed above, the AB 2588 data were judged to have the greatest potential for developing the speciated emission profiles necessary to quantify HAP emissions.

Several regulatory agencies in California were contacted, including: California Air Resources Board (CARB), South Coast Air Quality Management District (SCAQMD), Bay Area Air Quality Management District (BAAQMD), and Kern County Air Pollution Control District. Discussions with regulatory personnel indicated that the AB 2588 information was still being assembled and had undergone only minimal review by the various agencies. Therefore, it was decided that dealing directly with the

respective refiners would be the most efficient way to collect the AB 2588 data.

California refiners were contacted to identify the specific information they have submitted under AB 2588. The Western States Petroleum Association (WSPA) was contacted to facilitate industry contact and data collection. Of particular interest to the project was industry methodology to quantify HAP emissions and actual test results (e.g., stack testing, stream HAP analyses). Eight companies and 11 refineries were represented in the AB 2588 reports submitted.

The last phase of the study involved an analysis of the data to derive HAP emission factors and develop methodologies for extrapolating these factors to a national level. Information from the California refineries was compiled into a database (the California Refinery Database) and emission factors were derived for each subcategory of emission sources.

### 1.3 DATABASE LIMITATIONS

There are a number of shortcomings in the California refinery database that limit the usefulness of the results of this study. First, there were not enough data provided on all subcategories of emission sources to allow for the development of highly reliable HAP emission factors for all subcategories. For example, in some cases only one refinery reported HAP emissions for a particular emission source. Thus, the factors derived in these cases may not be representative of the entire industry. Specific details on the limitations of the database with respect to each emission source type (process vents, equipment leaks, etc.) are discussed in the relevant sections of this report.

Additionally, the AB 2588 reports were not required to include several CAA HAP's that are prevalent in refining operations. The missing HAP's include hexane, methyl-ethyl ketone (MEK) methyl-tert-butyl-ether (MTBE), and 2-2-4, trimethylpentane (iso-octane). Thus, no HAP emission factors were derived for these important pollutants; and therefore, total HAP emission factors could not be determined.

A second problem resulting from the database shortcomings was that not all project objectives were met. As indicated in Section 1.1, one goal was to develop nationwide HAP emission estimates for each emission source type. However, this was not possible because of the lack of representative emission factors for all emission source subcategories, coupled with a lack of sufficient data on certain key process parameters. For example, little information was provided on such key parameters as equipment counts by process unit, capacities of individual storage tanks, types of wastewater collection units present, and types of receiving vessels used to transfer products.

Another goal that could not be met was to provide estimates of total volatile organic compound (VOC) emissions. The AB 2588 reports included only the required compounds, not total VOC.

Despite these limitations, the study does provide useful information on emissions of a number of HAP's from petroleum refining operations. The HAP emission factors listed in this report could certainly be used to perform screening assessments that would yield a rough estimate of HAP emissions for a given facility and assist in determining where additional data are needed. Additionally, the study does indicate the relative contribution to total HAP emissions by each emission source type.

## 2.0 PROCESS VENTS AND COMBUSTION SOURCES

### 2.1 BACKGROUND INFORMATION

The major sources of atmospheric process emissions in petroleum refineries are sulfur recovery, fluid catalytic cracking (FCC) catalyst regeneration, and process heaters/boilers.<sup>1</sup> Other less significant sources include vacuum distillation, coking, reformer catalyst regeneration, blowdown/flare systems, and compressor engine exhaust.

Sources of hazardous air pollutants (HAP's) reported by California refineries in AB 2588 reports include process heaters/boilers, internal combustion engines and turbines, flares, incinerators, FCC units with and without CO boilers, sulfur recovery units, and coke handling. Information about other process emission sources, control technology, and potential emissions may be found in Assessment of Atmospheric Emissions from Petroleum Refineries<sup>1</sup> and AB 2588 Emission Estimation Techniques for Petroleum Refineries and Bulk Terminals.<sup>2</sup>

#### 2.1.1 Process Heaters and Boilers

Process heaters are used extensively in refining operations to heat feed materials and supply heat to distillation operations and reaction processes. They are designed to raise temperatures up to 1,000°F. The fuel may be refinery fuel gas, natural gas, fuel oil, or oil/gas mixtures.

Heat for refinery operations is also provided by steam that is produced in boilers. These boilers generally are fired by fuel oil, natural gas, or oil/gas mixtures.

Process heaters and boilers are the greatest source of combustion emissions in a refinery. The type and quantity of emissions from this source depend on the operating conditions of the unit and the type of fuel burned, as well as the nature of the contaminants in the fuel. Reported HAP emissions from process heaters and boilers include acetaldehyde, benzene,

formaldehyde, phenol, metals, radionuclides, and toluene, and in the metals category, arsenic, beryllium, cadmium, total chromium, hexavalent chromium, lead, manganese, mercury, nickel, and selenium compounds.

#### 2.1.1.2 Internal Combustion Engines and Turbines

Reciprocating and gas turbine engines are used to power high-pressure compressors or in cogeneration applications. They are usually fired with natural gas or refinery fuel gas. High-pressure compressors are used in refinery process units such as hydrodesulfurization, catalytic reforming, hydrocracking, and in auxiliary facilities.

The HAP emissions reported from process gas-fired compressor engines include acetaldehyde, benzene, formaldehyde, metals, and phenol. For natural gas-fired engines, reported HAP emissions include acetaldehyde, benzene, formaldehyde, toluene, and xylene.

#### 2.1.1.3 Flares

Flares in combination with blowdown systems are common to all petroleum refineries. Flares destroy gaseous emissions from the blowdown system by combustion. The gaseous emissions are hydrocarbon gases and other waste gas streams that are continuously or intermittently released from process equipment. The releases occur for various reasons, such as pressure control, emergency pressure relief, vent seal leaks, process equipment leaks, and release of noncondensable gases.

The type and amount of flare emissions depends on the composition of the gas being flared, the flow rate, and the flare type and design. There are elevated flares and enclosed ground-level flares. They may be designed for routine or emergency use.

Reported HAP emissions from flares include acetaldehyde, benzene, ethylene dibromide, ethylene dichloride, and metals.

#### 2.1.1.4 Catalytic Cracking with CO Boilers

In catalytic cracking, catalysts are used to break down heavy oils into lighter products. Spent catalyst in fluidized catalytic cracking units (FCC) or moving-bed catalyst cracking units is transferred to a regenerator, where coke deposits are

removed from the surface of the catalyst by partial combustion. Because of incomplete combustion in the regenerator, the flue gas from the regenerator usually has a high carbon monoxide (CO) concentration.

The CO emissions from FCC units regenerators are generally controlled using CO boilers. Furthermore, CO boilers recover energy contained in the flue gas to produce process heat for various refinery processes.

Hazardous air pollutants that were reported in the process streams from catalytic crackers and CO boilers include benzene, formaldehyde, acetaldehyde, 1,3-butadiene, phenol, and metals.

#### 2.1.5 Sulfur Recovery Units

Sulfur recovery units are used in petroleum refineries to convert hydrogen sulfide ( $H_2S$ ) to elemental sulfur. In recent years, the Claus process has been the accepted method for sulfur recovery. However, because this process is not totally efficient in producing elemental sulfur, tail gas from the sulfur recovery unit can be a major source of emissions.

The tail gas from a Claus unit is incinerated before it passes to the atmosphere or is subjected to further treatment. Because the heating value of tail gas is low, auxiliary fuel is needed. Reported emissions from Claus tail gas incineration include carbonyl sulfide, carbon disulfide, benzene, and formaldehyde.

### 2.2 METHOD FOR DEVELOPING HAZARDOUS AIR POLLUTANT EMISSION FACTORS FOR PROCESS VENTS AND COMBUSTION SOURCES

The HAP emission factors for process vents and combustion sources were developed by compiling information from California refineries and generating correlations between HAP emissions and refinery process charge capacity, as explained below.

#### 2.2.1 California Refinery Process Vent and Combustion Source Database

The minimum information required to set up the database for combustion sources was:

- fuel type;
- annual average emissions by HAP (lb/yr);

- fuel usage (Mbbbl or MSCF); and
- refinery process assignment.

For process vents, the minimum information was annual average emissions by HAP (lb/yr). Additional information about emission controls and estimation method was compiled when available.

Seventeen HAP's were reported as being released from process vents and combustion sources. Table 2-1 shows the various HAP's per source type and fuel type (if applicable) reported by California refineries and included in the database.

Tables 2-2 through 2-9 present the HAP emissions per process vent and combustion source type per refinery process reported by each of the 8 California refineries included in this database. Emissions data for refineries B, E, and H are not included in the database because refineries B and H did not report emissions data by HAP, and refinery E did not provide information to determine emissions data per refinery process. The annual average emissions by HAP from refinery process vents and combustion sources were obtained from Form "PRO-Process and Emittents Data" used by California refineries to comply with AB 2588.

The emission estimation method used and reported varied for the specific emission sources and HAP's reported. In general, emission estimations were based on South Coast Air Quality Management District (SCAQMD) emission factors, Bay Area Air Quality Management District (BAAQMD) emission factors, and other available emission factors. When available, data from mandated source testing and from the Western States Petroleum Association's (WSPA) pooled source testing were also used. Catalytic crackers, CO boilers, and fuel oil-fired boilers are sources that must be tested under AB 2588 regulations.

The HAP emissions from process vents and combustion sources reported by each refinery in the database are summarized in Table 2-10. Process heaters and boilers are the main contributors to process emissions.

### 2.2.2 Development of Hazardous Air Pollutant Emission Factors

Based on an analysis of the tabulated emission data, HAP emission factors by refinery process were developed for each of the emission sources listed in Section 2.1. Emission factors expressed as lb/yr per 1,000 bbl/sday refinery process charge capacity were obtained.

Specific HAP emission factors were obtained by dividing the reported HAP emissions from each refinery (for a specific emission source, fuel type, and refinery process) by the total refinery process charge capacity of those refineries reporting the specific HAP. Types and capacities of refinery processes included in the database were taken from the Oil and Gas Journal's January 1990 Annual Refining Survey.<sup>3</sup>

Table 2-11 presents the HAP emission factors as lb/yr per 1,000 bbl/sday refinery process charge capacity developed for each refinery process included in the California refinery database. Refinery processes were assigned to each emission source using the general flow diagrams provided by the California refineries.

For combustion sources, additional emission factors expressed as lb/MMBtu are provided in Table 2-12. When the information from a California refinery did not include the Btu content for a specific fuel type, the average value reported by all California refineries in the database was used. Furthermore, because of the lack of fuel usage data for some sources, actual emissions data reported by some California refineries were not included in the emission factor calculations.

Because of the difficulty in identifying the refinery processes associated with a specific utility boiler or flare, only emission factors expressed as lb/MMBtu were developed.

2.2.2.1 Analysis of Hazardous Air Pollutant Emission Factors (lb/yr per 1,000 bbl/sday process charge capacity). The HAP emission factors for process vents and combustion sources range from 0.00022 to 27.9 lb/yr per 1,000 bbl/sday. The lowest emission factor is for mercury compounds (asphalt process heater

firing process gas) and the highest emission factor is for toluene (alkylation-polymerization turbine firing process gas).

For process heaters firing process gas, which was the most widely reported fuel type, the HAP's emitted in the greatest amount per 1,000 bbl of refinery process charge capacity were formaldehyde and toluene. Toluene was the HAP with the highest emission factor in crude units, vacuum distillation, thermal operations, catalytic cracking, catalytic reforming, catalytic hydrocracking, catalytic hydrotreating, lubes, asphalt, and hydrogen processes. Formaldehyde had the highest emission factor for the aromatics-isomerization process.

For boilers firing process gas, the highest HAP emission factors were obtained for acetaldehyde, formaldehyde, and toluene.

For internal combustion (IC) engines and turbines using process gas, benzene, formaldehyde, and toluene were the HAP's with the highest emission factors.

For FCC units with CO boilers firing process gas and CO gas, the highest emission factors were obtained for manganese and nickel compounds. For FCC units without CO boilers, the largest emission factor was developed for phenol.

It is important to mention that the representativeness of the data used to develop the HAP emission factors varies, depending on the emission source and fuel type (applicable for combustion sources). In some cases, only one refinery reported a particular emission source and/or fuel type. Table 2-1 may be useful in determining specific data representativeness.

2.2.2.2 Analysis of Hazardous Air Pollutant Emission Factors (lb/MMBtu). The HAP emission factors expressed as lb/MMBtu for process vents and combustion sources range from  $0.00671 \times 10^{-6}$  to 2.82 lb/MMBtu. The lowest emission factor is for phenol (FCC units with CO boiler firing fuel oil) and the highest emission factor is for manganese compounds (boiler firing fuel oil).

In general, these HAP emission factors follow the same pattern as the HAP emission factors expressed as lb/yr per

1,000 bbl/sday refinery process charge capacity. For IC engines and turbines using natural gas, the highest HAP emission factors were obtained for benzene and formaldehyde. For flares, toluene was the HAP with the highest emission factor. Table 2-1 may be useful in determining specific data representativeness.

### 2.3 REFERENCES

1. U.S. Environmental Protection Agency, Assessment of Atmospheric Emissions from Petroleum Refining. Office of Research and Development. Washington, D.C. EPA-600/2-80-075. July 1980.
2. Wright, D.A., M.N. Menon, and S.H. Peoples, Radian Corporation, AB 2588 Emission Estimation Techniques for Petroleum Refineries and Bulk Terminals - Final Report, prepared for Western States Petroleum Association, July 21, 1989.
3. Thrash, L.A. Annual Refining Survey. Oil & Gas Journal. March 26, 1990.

TABLE 2-1. HAZARDOUS AIR POLLUTANT REPORTED FOR COMBUSTION SOURCES  
AND PROCESS VENTS BY EACH REFINERY

| HAP          | Process heaters <sup>a</sup> | Boilers <sup>b</sup> | IC Engines <sup>c</sup> | Turbines <sup>c</sup> | Flares <sup>c</sup> |
|--------------|------------------------------|----------------------|-------------------------|-----------------------|---------------------|
| Acetaldehyde | A,C,G,I,J,K                  | A,C,D,G,I,J,K        | I,J                     | A,J                   | A,G,I,K             |
| As Compounds | F,I,K                        | -                    | -                       | -                     | I,K                 |
| Benzene      | A,F,G                        | A,D,G,I,K            | F,I,J,K                 | A,F,J                 | C,G                 |
| Be Compounds | F                            | -                    | -                       | -                     | -                   |
| Cd Compounds | F,I,K                        | -                    | -                       | -                     | I,K                 |
| Cr Compounds | A,C,I,J,K                    | A,C,J,K              | -                       | A                     | A,I,K               |
| Cresols      | -                            | -                    | -                       | -                     | -                   |
| Formaldehyde | A,C,F,G,I,J,K                | A,C,D,G,I,J,K        | F,I,J                   | A,F,J                 | A,C,G,I,K           |
| Pb Compounds | F                            | I,K                  | -                       | -                     | -                   |
| Mg Compounds | A,C,F,I,K                    | A,C,I,J,K            | -                       | A                     | A,I,K               |
| Hg Compounds | A,C,F,I,J,K                  | A,C,I,J,K            | -                       | A                     | A,I,K               |
| Napthalene   | A,C,J,K                      | A,C,J,K              | J                       | A,J                   | A,K                 |
| Ni Compounds | F,I,K                        | A,C,I,J,K            | -                       | A                     | I,K                 |
| Phenol       | A,C,I,J,K                    | A,C,I,J,K            | -                       | A                     | A,I,K               |
| Se Compounds | -                            | -                    | -                       | -                     | -                   |
| Toluene      | A,C,G,I,K                    | A,C,D,G,I,K          | I,J                     | A,J                   | A,C,G,I             |
| Xylene       | K                            | D                    | I,J                     | J                     | -                   |

(continued)

TABLE 2-1. (Continued)

| HAP          | Incinerators <sup>d</sup> | FCCU w/CO boiler <sup>e</sup> | FCCU w/o CO boiler <sup>e</sup> | Sulfur recovery units | Coke handling |
|--------------|---------------------------|-------------------------------|---------------------------------|-----------------------|---------------|
| Acetaldehyde | I                         | I,J                           | -                               | K                     | -             |
| As Compounds | -                         | C                             | K                               | -                     | -             |
| Benzene      | -                         | -                             | -                               | J                     | -             |
| Be Compounds | -                         | C                             | -                               | -                     | -             |
| Cd Compounds | -                         | C,I                           | -                               | -                     | -             |
| Cr Compounds | -                         | C                             | -                               | -                     | -             |
| Cresols      | -                         | C                             | -                               | -                     | -             |
| Formaldehyde | -                         | C,I,J                         | -                               | K                     | -             |
| Pb Compounds | -                         | C,I                           | -                               | -                     | -             |
| Mg Compounds | -                         | C,I                           | K                               | -                     | -             |
| Hg Compounds | -                         | C,I                           | K                               | -                     | -             |
| Napthalene   | -                         | -                             | K                               | -                     | -             |
| Ni Compounds | -                         | C,I,J                         | K                               | -                     | K             |
| Phenol       | -                         | C,I                           | K                               | -                     | -             |
| Se Compounds | -                         | C                             | -                               | -                     | -             |
| Toluene      | -                         | -                             | -                               | -                     | -             |
| Xylene       | -                         | -                             | -                               | -                     | -             |

<sup>a</sup>Process gas, natural gas and fuel oil.

<sup>b</sup>Process gas, natural gas, fuel oil, and others.

<sup>c</sup>Process gas and natural gas.

<sup>d</sup>Process gas.

<sup>e</sup>Process gas, CO gas, fresh feed, and fuel oil.

TABLE 2-2. REPORTED HAP EMISSIONS BY PROCESS VENT AND COMBUSTION SOURCE - REFINERY A

| Refinery process* | Process vent/<br>combustion source type | Fuel type   | Heat Input** | HAP Emissions (lb/yr) |         |                |                   |                         |                  |                  | Phenol          | Toluene |
|-------------------|---|-------------|--------------|-----------------------|---------|----------------|-------------------|-------------------------|------------------|------------------|-----------------|---------|
|                   |   |             |              | Acetal-<br>dehyde     | Benzene | Chro-<br>comp. | Formal-<br>dehyde | Man-<br>ganese<br>comp. | Mercury<br>comp. | Naph-<br>thalene | Nickel<br>comp. |         |
| H                 | Process heater                          | Process gas |              | 4.04                  | 0.7     | 0.06           | 16.1              | 0.8                     | 0.04             | 4.25             | 1.05            | 63.5    |
| M                 | Process heater                          | Process gas |              | 88                    | 7.1     | 0.92           | 30                |                         | 0.92             | 18.3             | 1.53            |         |
| M                 | Process heater                          | Process gas |              | 88.8                  | 6.9     | 0.93           | 30.2              |                         | 0.93             | 18.5             | 1.54            |         |
| F                 | Process heater                          | Process gas |              | 15.5                  | 3.8     | 0.23           | 62                | 3.08                    | 0.16             | 16.3             | 4.01            | 244     |
| H                 | Process heater                          | Process gas |              | 2.42                  | 0.5     | 0.04           | 9.67              | 0.48                    | 0.03             | 2.54             | 0.63            | 38      |
| D                 | Process heater                          | Process gas |              | 11.5                  | 2.4     | 0.17           | 45.9              | 2.28                    | 0.12             | 12.1             | 2.97            | 180     |
| D                 | Process heater                          | Process gas |              | 1.76                  | 0.3     | 0.03           | 7.05              | 0.35                    | 0.02             | 1.85             | 0.46            | 27.7    |
| E                 | Process heater                          | Process gas |              | 9.91                  | 1.9     | 0.15           | 39.6              | 1.97                    | 0.1              | 10.4             | 2.56            | 156     |
| E                 | Process heater                          | Process gas |              | 7.78                  | 1.7     | 0.12           | 31.1              | 1.54                    | 0.08             | 8.17             | 2.01            | 122     |
| E                 | Process heater                          | Process gas |              | 6.61                  | 1.3     | 0.1            | 26.4              | 1.31                    | 0.07             | 6.94             | 1.71            | 104     |
| E                 | Process heater                          | Process gas |              | 2.19                  | 0.4     | 0.03           | 8.77              | 0.44                    | 0.02             | 2.3              | 0.57            | 34.4    |
| E                 | Process heater                          | Process gas |              | 2.29                  | 0.4     | 0.03           | 9.18              | 0.46                    | 0.02             | 2.41             | 0.59            | 36      |
| E                 | Process heater                          | Process gas |              | 0.32                  |         | 0.005          | 1.27              | 0.06                    | 0.003            | 0.33             | 0.08            | 5       |
| D                 | Boiler                                  | Process gas |              | 2.74                  |         | 0.12           | 7.64              | 0.22                    | 0.46             | 1.36             | 1.32            | 405     |
| D                 | Boiler                                  | Process gas |              |                       | 2       |                | 55.6              |                         |                  |                  |                 |         |
| D                 | Boiler                                  | Process gas |              | 4.43                  |         | 0.2            | 12.4              | 0.36                    | 0.75             | 2.2              | 2.13            | 655     |
| D                 | Boiler                                  | Process gas |              |                       | 2.4     |                | 68.6              |                         |                  |                  |                 |         |
| D                 | Boiler                                  | Process gas |              | 2.18                  |         | 0.1            | 6.08              | 0.18                    | 0.37             | 1.08             | 1.05            | 322     |
| D                 | Boiler                                  | Process gas |              |                       | 0.6     |                | 17.1              |                         |                  |                  |                 |         |
| E                 | Boiler                                  | Process gas |              | 2.26                  |         | 0.1            | 6.31              | 0.18                    | 0.38             | 1.12             | 1.09            | 334     |
| E                 | Boiler                                  | Process gas |              |                       | 0.2     |                | 19.2              |                         |                  |                  |                 |         |
| UT                | Boiler                                  | Process gas |              | 2.97                  |         | 0.13           | 8.27              | 0.24                    | 0.5              | 1.47             | 1.43            | 438     |
| UT                | Boiler                                  | Process gas |              |                       | 1.5     |                | 41.5              |                         |                  |                  |                 |         |
| UT                | Boiler                                  | Process gas |              | 2.64                  |         | 0.12           | 7.38              | 0.21                    | 0.45             | 1.31             | 1.27            | 391     |
| UT                | Boiler                                  | Process gas |              |                       | 1.7     |                | 46.3              |                         |                  |                  |                 |         |
| F                 | Turbine                                 | Process gas |              | 4.42                  | 7.3     | 0.2            | 12.3              | 0.36                    | 0.74             | 2.19             | 2.13            | 653     |
| D                 | Turbine                                 | Process gas |              | 4.36                  | 6.7     | 0.2            | 12.2              | 0.35                    | 0.73             | 2.16             | 2.1             | 644     |
| D                 | Turbine                                 | Process gas |              | 9.52                  | 10.8    | 0.43           | 26.6              | 0.77                    | 1.6              | 4.71             | 4.58            | 1,410   |
| I                 | Turbine                                 | Process gas |              | 3.02                  | 5.3     | 0.14           | 8.42              | 0.24                    | 0.51             | 1.5              | 1.45            | 446     |

(continued)

TABLE 2-2. (Continued)

| Refinery process*      | Process vent/<br>combustion<br>source type | Fuel<br>type | Heat<br>input** | Acetal-<br>dehyde | Benzene | Chro-<br>comp. | HAP Emissions (lb/yr) |                         |                  |                  |                 |        |
|------------------------|--|--------------|-----------------|-------------------|---------|----------------|-----------------------|-------------------------|------------------|------------------|-----------------|--------|
|                        |  |              |                 |                   |         |                | Formal-<br>dehyde     | Man-<br>ganese<br>comp. | Mercury<br>comp. | Naph-<br>thalene | Nickel<br>comp. | Phenol |
| I                      | Boiler                                     | Process gas  |                 | 2.58              | 1.7     | 0.12           | 7.19                  | 0.21                    | 0.43             | 1.28             | 1.24            | 0.65   |
| F                      | Boiler                                     | Process gas  |                 | 2.68              |         | 0.12           | 7.48                  | 0.22                    | 0.45             | 1.33             | 1.29            | 0.68   |
| F                      | Boiler                                     | Process gas  |                 |                   | 1.3     |                | 36.5                  |                         |                  |                  |                 |        |
| UT                     | Flare                                      | Process gas  |                 | 2.64              |         | 0.008          | 10.6                  | 0.1                     | 0.005            | 2.77             |                 | 0.68   |
| UT                     | Flare                                      | Process gas  |                 | 17.7              |         | 0.05           | 70.7                  | 0.7                     | 0.04             | 18.6             |                 | 4.58   |
| UT                     | Flare                                      | Process gas  |                 | 20.4              |         | 0.06           | 81.6                  | 0.81                    | 0.04             | 21.4             |                 | 5.28   |
| Total emissions by HAP |  |              |                 | 326               | 68.9    | 4.91           | 935                   | 17.9                    | 9.97             | 169              | 21.1            | 41.3   |
|                        |  |              |                 |                   |         |                |                       |                         |                  |                  |                 | 8,130  |

\*Refinery process code:

A - Crude unit

B - Vacuum distillation

C - Thermal operations

D - Catalytic cracking

E - Catalytic reforming

F - Catalytic hydrocracking

G - Catalytic hydrorefining

H - Catalytic hydrotreating

I - Alkylation/polymerization

J - Aromatics/isomerization

K - Lubes

L - Asphalt

M - Hydrogen

N - Coke

O - Sulfur

UT - Utilities

\*\* Confidential for this refinery.

TABLE 2-3. REPORTED HAP EMISSIONS BY PROCESS VENT AND COMBUSTION SOURCE - REFINERY C

| Refinery process | Process vent/<br>combustion<br>source type | Fuel<br>type | Fuel<br>usage/yr | HAP Emissions (lb/yr)   |                  |                  |                            |                       |                        |                 |                            |               |                         | Selenium<br>comp. | Toluene<br>comp. |                  |                           |                 |
|------------------|--|--------------|------------------|-------------------------|------------------|------------------|----------------------------|-----------------------|------------------------|-----------------|----------------------------|---------------|-------------------------|-------------------|------------------|------------------|---------------------------|-----------------|
|                  |  |              |                  | Acetal-<br>dehyde comp. | Arsenic<br>comp. | Benzene<br>comp. | Beryl-<br>lithium<br>comp. | Cad-<br>mium<br>comp. | Chro-<br>mium<br>comp. | Cresol<br>comp. | Formal-<br>dehyde<br>comp. | Lead<br>comp. | Man-<br>ganese<br>comp. |                   |                  | Mercury<br>comp. | Naph-<br>thalene<br>comp. | Nickel<br>comp. |
| UT               | Boiler                                     | Process gas  | 1,460,000 MSCF   | 3.2                     |                  |                  |                            |                       |                        |                 |                            | 23            | 0.59                    | 0.0878            | 3.37             | 4.63             | 2.56                      | 818             |
| UT               | Boiler                                     | Process gas  | 3,130,000 MSCF   | 1.07                    |                  |                  |                            |                       |                        |                 |                            | 7.67          | 0.197                   | 0.0293            | 1.13             | 1.55             | 0.854                     | 273             |
| UT               | Boiler                                     | Process gas  | 799,000 MSCF     | 4.31                    |                  |                  |                            |                       |                        | 0.151           |                            | 4.33          | 0.158                   | 0.978             | 1.15             | 0.374            | 0.137                     | 224             |
| UT               | Boiler                                     | Process gas  | 5,060,000 MSCF   | 4.24                    |                  |                  |                            |                       |                        | 0.149           |                            | 4.26          | 0.156                   | 0.963             | 1.13             | 0.368            | 0.134                     | 221             |
| UT               | CO boiler                                  | Process gas  | 1,030,000 MSCF   |                         |                  |                  |                            |                       |                        |                 | 0.00298                    |               |                         |                   |                  |                  | 0.00284                   |                 |
| D                | CO boiler                                  | CO gas       | 26,200,000 MSCF  | 4.2                     |                  |                  | 4.2                        | 31.4                  |                        |                 | 0.325                      | 28.9          | 176                     |                   |                  | 121              | 0.313                     | 84              |
| UT               | CO boiler                                  | Process gas  | 700,000 MSCF     |                         |                  |                  |                            |                       |                        |                 | 0.00728                    |               |                         |                   |                  |                  | 0.007                     |                 |
| D                | CO boiler                                  | Fresh feed   | 7,430 Mbbbl      |                         | 0.183            |                  |                            |                       |                        |                 |                            | 3.2           |                         |                   |                  |                  |                           |                 |
| D                | CO boiler                                  | Fresh feed   | 7,430 Mbbbl      |                         | 0.183            |                  |                            |                       |                        |                 |                            | 3.2           |                         |                   |                  |                  |                           |                 |
| UT               | CO boiler                                  | Process gas  | 664,000 MSCF     |                         |                  |                  |                            |                       |                        |                 | 0.0069                     |               |                         |                   |                  |                  | 0.00664                   |                 |
| UT               | CO boiler                                  | Other        | 2,930 Mgal       |                         | 1.86             |                  | 1.86                       | 1.86                  |                        |                 | 0.000673                   | 5.12          |                         | 0.186             |                  | 17               | 0.000644                  | 6.05            |
| D                | CO boiler                                  | CO gas       | 26,200,000 MSCF  | 4.2                     |                  |                  | 4.2                        | 31.4                  |                        |                 | 0.325                      | 28.9          | 176                     |                   |                  | 121              | 0.313                     | 84              |
| UT               | CO boiler                                  | Other        | 2,930 Mgal       |                         | 1.86             |                  | 1.86                       | 1.86                  |                        |                 | 0.021                      | 5.12          |                         | 0.186             |                  | 17               | 0.0019                    | 6.05            |
| UT               | CO boiler                                  | Other        | 2,930 Mgal       |                         | 1.86             |                  | 1.86                       | 1.86                  |                        |                 | 0.000673                   | 5.12          |                         | 0.186             |                  | 17               | 0.000644                  | 6.05            |
| UT               | CO boiler                                  | CO gas       | 837,000 MSCF     |                         |                  |                  |                            |                       |                        |                 | 0.00249                    |               |                         |                   |                  |                  | 0.00237                   |                 |
| D                | CO boiler                                  | CO gas       | 26,200,000 MSCF  | 4.2                     |                  |                  | 4.2                        | 31.4                  |                        |                 | 0.325                      | 28.9          | 176                     |                   |                  | 121              | 0.313                     | 84              |
| UT/D             | CO boiler                                  | Fuel oil     | 21 Mgal          |                         |                  |                  |                            |                       |                        |                 | 0.0000223                  |               |                         |                   |                  |                  | 0.000021                  |                 |
| UT               | CO boiler                                  | Process gas  | 605,000 MSCF     |                         |                  |                  |                            |                       |                        |                 | 0.00629                    |               |                         |                   |                  |                  | 0.00605                   |                 |
| D                | CO boiler                                  | Fresh feed   | 7,430 Mbbbl      |                         | 0.183            |                  |                            |                       |                        |                 |                            | 3.2           |                         |                   |                  |                  |                           |                 |
| UT               | CO boiler                                  | Process gas  | 4,400 MSCF       |                         |                  |                  |                            |                       |                        |                 | 0.0000128                  |               |                         |                   |                  |                  | 0.0000121                 |                 |
| B                | Process heater                             | Process gas  | 379,000 MSCF     | 3.64                    |                  |                  |                            |                       | 0.0537                 |                 | 11.8                       | 0.48          | 0.0376                  | 3.81              |                  | 0.94             | 50.2                      |                 |
| E                | Process heater                             | Process gas  | 1,750,000 MSCF   | 2.61                    |                  |                  |                            |                       | 0.0385                 |                 | 8.46                       | 0.344         | 0.027                   | 2.73              |                  | 0.674            | 36                        |                 |
| E                | Process heater                             | Process gas  | 3,290,000 MSCF   | 4.91                    |                  |                  |                            |                       | 0.0725                 |                 | 15.9                       | 0.648         | 0.0508                  | 5.15              |                  | 1.27             | 67.8                      |                 |
| H                | Process heater                             | Process gas  | 121,000 MSCF     | 0.18                    |                  |                  |                            |                       | 0.00266                |                 | 0.584                      | 0.0238        | 0.00186                 | 0.189             |                  | 0.0465           | 2.48                      |                 |
| L                | Process heater                             | Process gas  | 25,000 MSCF      | 0.24                    |                  |                  |                            |                       | 0.00354                |                 | 0.776                      | 0.0317        | 0.00248                 | 0.251             |                  | 0.062            | 3.31                      |                 |
| D                | Process heater                             | Process gas  | 143,000 MSCF     | 1.37                    |                  |                  |                            |                       | 0.0202                 |                 | 4.45                       | 0.181         | 0.0142                  | 1.44              |                  | 0.354            | 18.9                      |                 |
| C                | Process heater                             | Process gas  | 276,000 MSCF     | 2.65                    |                  |                  |                            |                       | 0.0391                 |                 | 6.61                       | 0.35          | 0.0274                  | 2.78              |                  | 0.686            | 36.6                      |                 |
| A                | Process heater                             | Process gas  | 8,610 MSCF       | 0.0816                  |                  |                  |                            |                       | 0.00122                |                 | 0.268                      | 0.0109        | 0.000854                | 0.0865            |                  | 0.0213           | 1.14                      |                 |

(continued)

(continued)

TABLE 2-3. (Continued)

| Refinery process | Process vent/<br>combustion<br>source type | Fuel<br>type | Fuel<br>usage/yr | HAP Emissions (lb/yr)      |                  |                  |                            |                       |                        |                 |                            |               |                         |                  |                           |                 |                 |                        |                  |       |
|------------------|--|--------------|------------------|----------------------------|------------------|------------------|----------------------------|-----------------------|------------------------|-----------------|----------------------------|---------------|-------------------------|------------------|---------------------------|-----------------|-----------------|------------------------|------------------|-------|
|                  |  |              |                  | Acetal-<br>dehyde<br>comp. | Arsenic<br>comp. | Benzene<br>comp. | Beryl-<br>lithium<br>comp. | Cad-<br>mium<br>comp. | Chro-<br>mium<br>comp. | Cresol<br>comp. | Formal-<br>dehyde<br>comp. | Lead<br>comp. | Man-<br>ganese<br>comp. | Mercury<br>comp. | Naph-<br>thalene<br>comp. | Nickel<br>comp. | Phenol<br>comp. | Selen-<br>ium<br>comp. | Toluene<br>comp. |       |
| E                | Process heater                             | Process gas  | 485,000 MSCF     | 4.65                       |                  |                  |                            |                       | 0.0686                 |                 |                            |               | 15.1                    |                  | 0.614                     | 0.0481          | 4.87            |                        | 1.2              | 64.2  |
| K                | Process heater                             | Process gas  | 175,000 MSCF     | 1.68                       |                  |                  |                            |                       | 0.0248                 |                 |                            |               | 5.45                    |                  | 0.222                     | 0.0174          | 1.76            |                        | 0.434            | 23.2  |
| M                | Process heater                             | Process gas  | 2,760,000 MSCF   | 71.5                       |                  |                  |                            |                       | 0.745                  |                 |                            |               | 24.3                    |                  |                           | 0.745           | 14.9            |                        | 1.24             | 295   |
| H                | Process heater                             | Process gas  | 90,000 MSCF      | 0.863                      |                  |                  |                            |                       | 0.0127                 |                 |                            |               | 2.8                     |                  | 0.114                     | 0.00894         | 0.905           |                        | 0.223            | 11.9  |
| E                | Process heater                             | Process gas  | 372,000 MSCF     | 0.555                      |                  |                  |                            |                       | 0.00819                |                 |                            |               | 1.8                     |                  | 0.0732                    | 0.00574         | 0.582           |                        | 0.143            | 7.66  |
| F                | Process heater                             | Process gas  | 243,000 MSCF     | 2.33                       |                  |                  |                            |                       | 0.0344                 |                 |                            |               | 7.57                    |                  | 0.308                     | 0.0241          | 2.44            |                        | 0.603            | 32.2  |
| M                | Process heater                             | Process gas  | 1,900,000 MSCF   | 49.2                       |                  |                  |                            |                       | 0.513                  |                 |                            |               | 16.8                    |                  |                           | 0.513           | 10.3            |                        | 0.855            | 203   |
| K                | Process heater                             | Process gas  | 41,000 MSCF      | 0.393                      |                  |                  |                            |                       | 0.00581                |                 |                            |               | 1.28                    |                  | 0.0519                    | 0.00407         | 0.412           |                        | 0.102            | 5.43  |
| F                | Process heater                             | Process gas  | 407,000 MSCF     | 3.9                        |                  |                  |                            |                       | 0.0576                 |                 |                            |               | 12.7                    |                  | 0.515                     | 0.0404          | 4.09            |                        | 1.01             | 53.9  |
| D                | Process heater                             | Process gas  | 714,000 MSCF     | 6.85                       |                  |                  |                            |                       | 0.101                  |                 |                            |               | 22.2                    |                  | 0.904                     | 0.0709          | 7.18            |                        | 1.77             | 94.5  |
| E                | Process heater                             | Process gas  | 307,000 MSCF     | 2.94                       |                  |                  |                            |                       | 0.0435                 |                 |                            |               | 9.56                    |                  | 0.389                     | 0.0305          | 3.09            |                        | 0.761            | 40.6  |
| H                | Process heater                             | Process gas  | 503,000 MSCF     | 4.82                       |                  |                  |                            |                       | 0.0712                 |                 |                            |               | 15.6                    |                  | 0.636                     | 0.0499          | 5.05            |                        | 1.25             | 66.5  |
| E                | Process heater                             | Process gas  | 231,000 MSCF     | 2.22                       |                  |                  |                            |                       | 0.0327                 |                 |                            |               | 7.19                    |                  | 0.292                     | 0.0229          | 2.32            |                        | 0.573            | 30.6  |
| A                | Process heater                             | Process gas  | 984,000 MSCF     | 3.53                       |                  |                  |                            |                       | 0.141                  |                 |                            |               | 30.9                    |                  | 1.26                      | 0.0987          | 3.99            |                        | 2.46             | 132   |
| C                | Process heater                             | Process gas  | 1,300,000 MSCF   | 1.94                       |                  |                  |                            |                       | 0.0287                 |                 |                            |               | 6.3                     |                  | 0.256                     | 0.0201          | 2.03            |                        | 0.502            | 26.8  |
| A                | Process heater                             | Process gas  | 9,100,000 MSCF   | 13.6                       |                  |                  |                            |                       | 0.201                  |                 |                            |               | 44.1                    |                  | 1.79                      | 0.141           | 14.2            |                        | 3.51             | 188   |
| UT               | Process heater                             | Process gas  | 662,000 MSCF     | 6.36                       |                  |                  |                            |                       | 0.0938                 |                 |                            |               | 20.6                    |                  | 0.839                     | 0.0658          | 6.66            |                        | 1.64             | 87.7  |
| K                | Process heater                             | Process gas  | 550,000 MSCF     | 5.28                       |                  |                  |                            |                       | 0.0779                 |                 |                            |               | 17.1                    |                  | 0.696                     | 0.0546          | 5.53            |                        | 1.36             | 72.8  |
| A                | Process heater                             | Process gas  | 77,400 MSCF      | 74.3                       |                  |                  |                            |                       | 0.011                  |                 |                            |               | 2.41                    |                  | 0.098                     | 0.00769         | 0.779           |                        | 0.192            | 10.3  |
| H                | Process heater                             | Process gas  | 162,000 MSCF     | 1.55                       |                  |                  |                            |                       | 0.0229                 |                 |                            |               | 5.03                    |                  | 0.205                     | 0.0161          | 1.63            |                        | 0.401            | 21.4  |
| F                | Process heater                             | Process gas  | 1,710,000 MSCF   | 2.55                       |                  |                  |                            |                       | 0.0377                 |                 |                            |               | 8.29                    |                  | 0.337                     | 0.0264          | 2.68            |                        | 0.661            | 35.3  |
| A                | Process heater                             | Process gas  | 391,000 MSCF     | 3.75                       |                  |                  |                            |                       | 0.0554                 |                 |                            |               | 12.2                    |                  | 0.495                     | 0.0388          | 3.93            |                        | 0.97             | 51.8  |
| B                | Process heater                             | Process gas  | 382,000 MSCF     | 3.67                       |                  |                  |                            |                       | 0.0541                 |                 |                            |               | 11.9                    |                  | 0.484                     | 0.038           | 3.85            |                        | 0.949            | 50.6  |
| F                | Process heater                             | Process gas  | 453,000 MSCF     | 4.35                       |                  |                  |                            |                       | 0.0642                 |                 |                            |               | 14.1                    |                  | 0.574                     | 0.045           | 4.56            |                        | 1.12             | 60    |
| H                | Process heater                             | Process gas  | 233,000 MSCF     | 2.24                       |                  |                  |                            |                       | 0.033                  |                 |                            |               | 7.27                    |                  | 0.295                     | 0.0232          | 2.35            |                        | 0.579            | 30.9  |
| B                | Process heater                             | Process gas  | 3,740,000 MSCF   | 5.58                       |                  |                  |                            |                       | 0.0823                 |                 |                            |               | 18.1                    |                  | 0.736                     | 0.0577          | 5.85            |                        | 1.44             | 77    |
| H                | Process heater                             | Process gas  | 5,800 MSCF       | 0.0556                     |                  |                  |                            |                       | 0.000821               |                 |                            |               | 0.181                   |                  | 0.00734                   | 0.000576        | 0.0583          |                        | 0.0144           | 0.768 |
| K                | Process heater                             | Process gas  | 90,000 MSCF      | 0.863                      |                  |                  |                            |                       | 0.0127                 |                 |                            |               | 2.8                     |                  | 0.114                     | 0.00894         | 0.905           |                        | 0.223            | 11.9  |

(continued)

(continued)

TABLE 2-3. (Continued)

| Refinery process*      | Process vent/<br>combustion<br>source type | Fuel<br>type | Fuel<br>usage/yr | HAP Emissions (lb/yr)      |                  |                  |                         |                       |                        |                 |                            |               |                         |                            |      | Mercury<br>comp. | Methyl<br>thale<br>comp. | Phenol<br>comp. | Sole-<br>nium<br>comp. |  |      |  |       |       |       |
|------------------------|--|--------------|------------------|----------------------------|------------------|------------------|-------------------------|-----------------------|------------------------|-----------------|----------------------------|---------------|-------------------------|----------------------------|------|------------------|--------------------------|-----------------|------------------------|--|------|--|-------|-------|-------|
|                        |  |              |                  | Acetal-<br>dehyde<br>comp. | Arsenic<br>comp. | Benzene<br>comp. | Beryl-<br>lium<br>comp. | Cad-<br>mium<br>comp. | Chro-<br>mium<br>comp. | Cresol<br>comp. | Formal-<br>dehyde<br>comp. | Lead<br>comp. | Man-<br>ganese<br>comp. | Formal-<br>dehyde<br>comp. |      |                  |                          |                 |                        |  |      |  |       |       |       |
| M                      | Process heater                             | Process gas  | 4,700,000 MSCF   | 18.9                       |                  |                  |                         |                       |                        | 0.197           |                            |               |                         |                            | 6.44 |                  |                          | 0.197           |                        |  | 3.94 |  | 0.329 |       | 78.2  |
| E                      | Process heater                             | Process gas  | 101,000 MSCF     | 0.971                      |                  |                  |                         |                       |                        | 0.0143          |                            |               |                         |                            | 3.15 |                  |                          | 0.128           |                        |  | 1.02 |  | 0.251 |       | 13.4  |
| E                      | Process heater                             | Process gas  | 4,050,000 MSCF   | 6.05                       |                  |                  |                         |                       |                        | 0.0893          |                            |               |                         |                            | 19.6 |                  |                          | 0.798           |                        |  | 6.34 |  | 1.56  |       | 83.5  |
| F                      | Process heater                             | Process gas  | 484,000 MSCF     | 4.65                       |                  |                  |                         |                       |                        | 0.0686          |                            |               |                         |                            | 15.1 |                  |                          | 0.613           |                        |  | 4.87 |  | 1.2   |       | 64.1  |
| M                      | Process heater                             | Process gas  | 8,530,000 MSCF   | 34.4                       |                  |                  |                         |                       |                        | 0.358           |                            |               |                         |                            | 11.7 |                  |                          | 0.347           |                        |  | 7.16 |  | 0.597 |       | 142   |
| A                      | Process heater                             | Process gas  | 1,760,000 MSCF   | 2.63                       |                  |                  |                         |                       |                        | 0.0388          |                            |               |                         |                            | 8.53 |                  |                          | 0.224           |                        |  | 2.76 |  | 0.68  |       | 36.3  |
| E                      | Process heater                             | Process gas  | 177,000 MSCF     | 1.7                        |                  |                  |                         |                       |                        | 0.0251          |                            |               |                         |                            | 5.51 |                  |                          | 0.496           |                        |  | 1.78 |  | 0.439 |       | 23.5  |
| B                      | Process heater                             | Process gas  | 2,520,000 MSCF   | 3.76                       |                  |                  |                         |                       |                        | 0.0555          |                            |               |                         |                            | 12.2 |                  |                          | 0.456           |                        |  | 3.94 |  | 0.972 |       | 51.9  |
| H                      | Process heater                             | Process gas  | 360,000 MSCF     | 3.45                       |                  |                  |                         |                       |                        | 0.051           |                            |               |                         |                            | 11.2 |                  |                          | 0.807           |                        |  | 3.62 |  | 0.893 |       | 47.7  |
| E                      | Process heater                             | Process gas  | 637,000 MSCF     | 6.11                       |                  |                  |                         |                       |                        | 0.0902          |                            |               |                         |                            | 19.8 |                  |                          | 0.807           |                        |  | 6.41 |  | 1.58  |       | 84.4  |
| F                      | Process heater                             | Process gas  | 11,000,000 MSCF  | 16.4                       |                  |                  |                         |                       |                        | 0.242           |                            |               |                         |                            | 53.2 |                  |                          | 2.16            |                        |  | 17.2 |  | 4.24  |       | 226   |
| A,B,C,<br>E,F,H        | Flare                                      | Process gas  | 360,000 MSCF     |                            |                  | 0.115            |                         |                       |                        |                 |                            |               |                         |                            | 23   |                  |                          |                 |                        |  |      |  |       | 0.057 |       |
| Total emissions by HAP |  |              |                  | 409                        | 18.2             | 0.489            | 18.2                    | 99.8                  | 4.39                   | 1.02            | 608                        | 102           | 549                     | 6                          | 196  | 421              |                          |                 |                        |  |      |  | 47.6  | 270   | 4,390 |

\*Refinery process code:

A = Crude unit

B = Vacuum distillation

C = Thermal operations

D = Catalytic cracking

E = Catalytic reforming

F = Catalytic hydrocracking

G = Catalytic hydrosulfiding

H = Catalytic hydrotreating

I = Alkylation/polymerization

J = Aromatics/isomerization

K = Lubric

L = Asphalt

M = Hydrogen

N = Coke

O = Sulfur

UT = Utilities

TABLE 2-4. REPORTED HAP EMISSIONS BY PROCESS VENT AND COMBUSTION SOURCE - REFINERY D

| Refinery process* | Process vent/<br>combustion source type | Fuel type   | Fuel usage/yr | HAP Emissions (lb/yr) |         |              |        |
|-------------------|---|-------------|---------------|-----------------------|---------|--------------|--------|
|                   |   |             |               | Acetaldehyde          | Benzene | Formaldehyde | Xylene |
| UT                | Boiler                                  | Other       | 59.4 MGal     |                       |         |              |        |
| UT                | Boiler                                  | Fuel oil    | 160 MGal      |                       | 1       |              |        |
| UT                | Boiler                                  | Fuel oil    | 154 MGal      |                       | 1       |              |        |
| UT                | Boiler                                  | Natural gas | 45 MSCF       | 2                     | 9       | 20           | 5      |
| UT                | Boiler                                  | Natural gas | 46.9 MSCF     | 2                     | 9       | 21           | 5      |
| UT                | Boiler                                  | Natural gas | 7.44 MSCF     |                       | 1       | 3            | 1      |
| UT                | Boiler                                  | Natural gas | 7.44 MSCF     |                       | 1       | 3            | 1      |
| A                 | Process heater                          | Fuel oil    | 109 MGal      |                       |         |              |        |
| B                 | Process heater                          | Natural gas | 19.3 MSCF     | 1                     | 4       | 9            | 2      |
| L                 | Process heater                          | Natural gas | 2.86 MSCF     |                       | 1       | 1            |        |
| A                 | Process heater                          | Natural gas | 22.5 MSCF     | 1                     | 4       | 10           | 2      |
| A                 | Process heater                          | Natural gas | 31.7 MSCF     | 1                     | 6       | 14           | 3      |
| L                 | Process heater                          | Natural gas | 1.33 MSCF     |                       |         | 1            |        |
| A                 | Process heater                          | Fuel oil    | 769 MGal      |                       |         |              |        |
| L                 | Process heater                          | Natural gas | 3.24 MSCF     |                       | 1       | 1            |        |
| L                 | Process heater                          | Natural gas | 2.86 MSCF     |                       | 1       | 1            |        |

| Total emissions by HAP  |                               |                             |                | 7 | 39 | 84 | 22 | 8 |
|-------------------------|-------------------------------|-----------------------------|----------------|---|----|----|----|---|
| *Refinery process code: |                               |                             |                |   |    |    |    |   |
| A - Crude unit          | E - Catalytic reforming       | J - Aromatics/isomerization | O - Sulfur     |   |    |    |    |   |
| B - Vacuum distillation | F - Catalytic hydrocracking   | K - Lubes                   | UT - Utilities |   |    |    |    |   |
| C - Thermal operations  | G - Catalytic hydrotreating   | L - Asphalt                 |                |   |    |    |    |   |
| D - Catalytic cracking  | H - Catalytic hydrotreating   | M - Hydrogen                |                |   |    |    |    |   |
|                         | I - Alkylation/polymerization | N - Coke                    |                |   |    |    |    |   |

TABLE 2-5. REPORTED HAP EMISSIONS BY PROCESS VENT AND COMBUSTION SOURCE - REFINERY F

| Refinery process* | Process vent/<br>combustion<br>source type | Fuel<br>type | Fuel<br>usage/yr | HAP Emissions (lb/yr) |         |                         |                       |                            |               |                         |                  |                 |  |
|-------------------|--|--------------|------------------|-----------------------|---------|-------------------------|-----------------------|----------------------------|---------------|-------------------------|------------------|-----------------|--|
|                   |  |              |                  | Arsenic<br>comp.      | Benzene | Beryl-<br>lium<br>comp. | Cad-<br>mium<br>comp. | Formal-<br>dehyde<br>comp. | Lead<br>comp. | Man-<br>ganese<br>comp. | Mercury<br>comp. | Nickel<br>comp. |  |
| UT                | Process heater                             | Natural gas  | 1,000 MSCF       |                       |         |                         |                       |                            | 0.2           |                         |                  |                 |  |
| UT                | IC engine                                  | Natural gas  | 29,500 MSCF      |                       | 45.5    |                         |                       |                            | 5900          |                         |                  |                 |  |
| UT                | IC engine                                  | Natural gas  | 38,100 MSCF      |                       | 58.7    |                         |                       |                            | 7600          |                         |                  |                 |  |
| UT                | IC engine                                  | Natural gas  | 38,100 MSCF      |                       | 58.7    |                         |                       |                            | 7600          |                         |                  |                 |  |
| F                 | Process heater                             | Process gas  | 700,000 MSCF     |                       | 2.3     |                         |                       |                            | 74            |                         |                  |                 |  |
| H                 | Process heater                             | Process gas  | 100,000 MSCF     |                       | 0.3     |                         |                       |                            | 10            |                         |                  |                 |  |
| A                 | Process heater                             | Process gas  | 500,000 MSCF     |                       | 0.2     |                         |                       |                            | 50            |                         |                  |                 |  |
| F                 | Process heater                             | Natural gas  | 486,000 MSCF     |                       | 3.1     |                         |                       |                            |               |                         |                  |                 |  |
| H                 | Process heater                             | Process gas  | 300,000 MSCF     |                       | 1       |                         |                       |                            | 30            |                         |                  |                 |  |
| F                 | Process heater                             | Process gas  | 420,000 MSCF     |                       | 1.4     |                         |                       |                            | 45            |                         |                  |                 |  |
| J                 | Process heater                             | Process gas  | 94,000 MSCF      |                       | 0.3     |                         |                       |                            | 9.4           |                         |                  |                 |  |
| E                 | Process heater                             | Process gas  | 200,000 MSCF     |                       | 0.7     |                         |                       |                            | 21            |                         |                  |                 |  |
| C                 | Process heater                             | Process gas  | 93,000 MSCF      |                       | 0.3     |                         |                       |                            | 10            |                         |                  |                 |  |
| E                 | Process heater                             | Process gas  |                  |                       |         |                         |                       |                            | 39            |                         |                  |                 |  |
| H                 | Process heater                             | Process gas  | 70,000 MSCF      |                       | 0.2     |                         |                       |                            | 7             |                         |                  |                 |  |
| K                 | Process heater                             | Process gas  | 4,000 MSCF       |                       | 0.2     |                         |                       |                            | 0.4           |                         |                  |                 |  |
| E                 | Process heater                             | Process gas  | 30,000 MSCF      |                       | 0.1     |                         |                       |                            | 3             |                         |                  |                 |  |
| H                 | Process heater                             | Fuel oil     | 400 Mgal         | 1.2                   | 7.2     | 0.3                     | 1                     | 24.6                       | 1.7           | 1.6                     | 0.2              | 76.6            |  |
| H                 | Process heater                             | Fuel oil     | 100 Mgal         | 0.3                   | 1.8     |                         | 0.2                   | 6.2                        | 0.4           | 0.4                     |                  | 19.2            |  |
| H                 | Process heater                             | Process gas  | 100,000 MSCF     |                       | 0.3     |                         |                       |                            | 11            |                         |                  |                 |  |
| E                 | Process heater                             | Process gas  |                  |                       |         |                         |                       |                            | 12            |                         |                  |                 |  |
| E                 | Process heater                             | Process gas  | 200,000 MSCF     |                       | 0.7     |                         |                       |                            | 23            |                         |                  |                 |  |
| H                 | Process heater                             | Fuel oil     | 400 Mgal         | 1.2                   | 7.2     | 0.3                     | 1                     | 24.6                       | 1.7           | 1.6                     | 0.2              | 76.6            |  |
| E                 | Process heater                             | Process gas  | 300,000 MSCF     |                       | 1       |                         |                       |                            | 29            |                         |                  |                 |  |
| E                 | Process heater                             | Process gas  | 300,000 MSCF     |                       | 1       |                         |                       |                            | 36            |                         |                  |                 |  |
| K                 | Process heater                             | Process gas  | 60,000 MSCF      |                       | 0.2     |                         |                       |                            | 6.2           |                         |                  |                 |  |
| C                 | Process heater                             | Process gas  | 400,000 MSCF     |                       | 1.3     |                         |                       |                            | 41            |                         |                  |                 |  |
| E                 | Process heater                             | Process gas  | 300,000 MSCF     |                       | 1       |                         |                       |                            | 33            |                         |                  |                 |  |
| F                 | Process heater                             | Process gas  | 150,000 MSCF     |                       | 0.5     |                         |                       |                            | 16            |                         |                  |                 |  |
| T                 | Process heater                             | Process gas  | 660,000 MSCF     |                       | 1.7     |                         |                       |                            | 66            |                         |                  |                 |  |

(continued)

TABLE 2-5. (Continued)

| Refinery process*      | Process vent/<br>combustion<br>source type | Fuel<br>type | Fuel<br>usage/yr | Arsenic<br>comp. | HAP Emissions (lb/yr)      |                       |                            |               |                         | Nickel<br>comp. |
|------------------------|--|--------------|------------------|------------------|----------------------------|-----------------------|----------------------------|---------------|-------------------------|-----------------|
|                        |  |              |                  |                  | Beryl-<br>lithium<br>comp. | Cad-<br>mium<br>comp. | Formal-<br>dehyde<br>comp. | Lead<br>comp. | Man-<br>ganese<br>comp. |                 |
| K                      | Process heater                             | Process gas  | 100,000 MSCF     |                  | 0.3                        |                       | 10                         |               |                         |                 |
| F                      | Process heater                             | Process gas  | 830,000 MSCF     |                  | 2.7                        |                       | 88                         |               |                         |                 |
| UT                     | Process heater                             | Process gas  | 660,000 MSCF     |                  | 2.2                        |                       | 61.2                       |               |                         |                 |
| H                      | Process heater                             | Process gas  | 100,000 MSCF     |                  | 0.3                        |                       | 16                         |               |                         |                 |
| E                      | Process heater                             | Process gas  | 80,000 MSCF      |                  | 0.3                        |                       | 8                          |               |                         |                 |
| K                      | Process heater                             | Process gas  | 55,000 MSCF      |                  | 0.2                        |                       | 6                          |               |                         |                 |
| J                      | Process heater                             | Process gas  | 106,000 MSCF     |                  | 0.3                        |                       | 10.6                       |               |                         |                 |
| C                      | Process heater                             | Process gas  | 1,000,000 MSCF   |                  | 3.1                        |                       | 100                        |               |                         |                 |
| E                      | Process heater                             | Process gas  | 90,000 MSCF      |                  | 0.3                        |                       | 9.2                        |               |                         |                 |
| H                      | Process heater                             | Process gas  | 200,000 MSCF     |                  | 0.7                        |                       | 22                         |               |                         |                 |
| UT                     | Process heater                             | Process gas  | 660,000 MSCF     |                  | 1.7                        |                       | 66                         |               |                         |                 |
| M                      | Process heater                             | Process gas  | 1,700,000 MSCF   |                  | 5.6                        |                       | 240                        |               |                         |                 |
| UT                     | Process heater                             | Process gas  | 230,000 MSCF     |                  | 0.8                        |                       | 21.3                       |               |                         |                 |
| C                      | Process heater                             | Process gas  | 200,000 MSCF     |                  | 0.7                        |                       | 21                         |               |                         |                 |
| E                      | Process heater                             | Process gas  | 300,000 MSCF     |                  | 1                          |                       | 32                         |               |                         |                 |
| UT                     | Process heater                             | Process gas  | 660,000 MSCF     |                  | 1.7                        |                       | 66                         |               |                         |                 |
| K                      | Process heater                             | Process gas  | 56,000 MSCF      |                  | 0.1                        |                       | 6                          |               |                         |                 |
| C                      | Process heater                             | Process gas  | 200,000 MSCF     |                  | 0.7                        |                       | 23                         |               |                         |                 |
| H                      | Process heater                             | Process gas  | 300,000 MSCF     |                  | 1                          |                       | 30                         |               |                         |                 |
| UT                     | Turbine                                    | Process gas  | 1,300,000 MSCF   |                  | 3.4                        |                       | 130                        |               |                         |                 |
| UT                     | Turbine                                    | Process gas  | 1,300,000 MSCF   |                  | 3.4                        |                       | 130                        |               |                         |                 |
| UT                     | Turbine                                    | Process gas  | 1,300,000 MSCF   |                  | 3.4                        |                       | 130                        |               |                         |                 |
| Total emissions by HAP |  |              |                  | 2.7              | 231                        | 0.6                   | 2.2                        | 23,000        | 3.8                     | 0.4             |
|                        |  |              |                  |                  |                            |                       |                            |               |                         | 172             |

\*Refinery process code:

A - Crude unit

B - Vacuum distillation

C - Thermal operations

D - Catalytic cracking

E - Catalytic reforming

F - Catalytic hydrocracking

G - Catalytic hydrotreating

H - Catalytic hydrotreating

I - Alkylation/polymerization

J - Aromatics/isomerization

K - Lubes

L - Asphalt

M - Hydrogen

N - Coke

O - Sulfur

UT - Utilities

TABLE 2-6. REPORTED HAP EMISSIONS BY PROCESS VENT AND COMBUSTION SOURCE - REFINERY G

| Refinery Process*      | Process vent/<br>combustion<br>source type | Fuel<br>type | Fuel<br>usage/yr | HAP Emissions (lb/yr) |         |                   |         |
|------------------------|--|--------------|------------------|-----------------------|---------|-------------------|---------|
|                        |  |              |                  | Acetal-<br>dehyde     | Benzene | Formal-<br>dehyde | Toluene |
| UT                     | Boiler                                     | Process gas  | 91,500 MSCF      | 0.07                  | 2.81    | 13.5              | 5.11    |
| UT                     | Boiler                                     | Process gas  | 91,500 MSCF      | 0.07                  | 2.81    | 13.5              | 5.11    |
| H                      | Process heater                             | Process gas  | 96,500 MSCF      | 0.08                  | 2.98    | 14.3              | 5.41    |
| F                      | Process heater                             | Process gas  | 103,000 MSCF     | 0.08                  | 3.16    | 15.1              | 5.74    |
| A                      | Process heater                             | Process gas  | 875,000 MSCF     | 0.73                  | 27      | 129               | 49      |
| F                      | Process heater                             | Process gas  | 41,700 MSCF      | 0.03                  | 1.28    | 6.2               | 2.34    |
| E                      | Process heater                             | Process gas  | 669,000 MSCF     | 0.28                  | 10.3    | 49.3              | 18.7    |
| H                      | Process heater                             | Process gas  | 91,000 MSCF      | 5.68                  | 2.6     | 13.4              | 5.08    |
| F                      | Process heater                             | Process gas  | 17,500 MSCF      | 0.01                  | 0.54    | 2.6               | 0.98    |
| H                      | Process heater                             | Process gas  | 72,000 MSCF      | 0.06                  | 2.21    | 1.6               | 4.02    |
| A                      | Process heater                             | Process gas  | 311,000 MSCF     | 0.26                  | 9.58    | 45.9              | 17.4    |
| A                      | Flare                                      | Natural gas  | 173 MSCF         | 0.02                  | 0.76    | 0.01              | 1.38    |
| Total emissions by HAP |  |              |                  | 7.4                   | 66.2    | 304               | 120     |

\*Refinery process code:

A - Crude unit

B - Vacuum distillation

C - Thermal operations

D - Catalytic cracking

E - Catalytic reforming

F - Catalytic hydrocracking

G - Catalytic hydrorefining

H - Catalytic hydrotreating

I - Alkylation/polymerization

J - Aromatics/isomerization

K - Lubes

L - Asphalt

M - Hydrogen

N - Coke

O - Sulfur

UT - Utilities

TABLE 2-7. REPORTED HAP EMISSIONS BY PROCESS VENT AND COMBUSTION SOURCE - REFINERY I

| Refinery process*      | Process vent/<br>combustion<br>source type | Fuel<br>type | Heat<br>Input/<br>yr | HAP Emissions (lb/yr) |                  |         |                       |                   |               |                         |                  |                 |         |         |        |
|------------------------|--|--------------|----------------------|-----------------------|------------------|---------|-----------------------|-------------------|---------------|-------------------------|------------------|-----------------|---------|---------|--------|
|                        |  |              |                      | Acetal-<br>dehyde     | Arsenic<br>comp. | Benzene | Cad-<br>mium<br>comp. | Formal-<br>dehyde | Lead<br>comp. | Man-<br>ganese<br>comp. | Mercury<br>comp. | Nickel<br>comp. | Phenol  | Toluene | Xylene |
| A                      | Process heater                             | Process gas  | 76.5                 |                       |                  |         |                       | 208               |               | 2.4                     | 0.533            | 0.266           | 21.3    | 159     |        |
| B                      | Process heater                             | Process gas  | 2.07                 |                       | 0.0675           |         | 0.0193                | 49.3              |               | 1.31                    | 0.0964           | 0.154           | 1.82    |         |        |
| B                      | Process heater                             | Process gas  | 2.09                 |                       | 0.0681           |         | 0.0195                | 49.8              |               | 1.32                    | 0.0973           | 0.156           | 1.84    |         |        |
| C                      | Process heater                             | Process gas  | 2.11                 |                       | 0.0686           |         | 0.0196                | 50.2              |               | 1.33                    | 0.098            | 0.157           | 1.85    |         |        |
| C                      | Process heater                             | Process gas  | 2.23                 |                       | 0.0725           |         | 0.0207                | 53                |               | 1.41                    | 0.104            | 0.166           | 1.96    |         |        |
| M                      | Process heater                             | Process gas  | 39.2                 |                       |                  |         |                       | 106               |               | 1.23                    | 0.273            | 0.136           | 10.9    | 81.2    |        |
| H                      | Process heater                             | Process gas  | 8.17                 |                       |                  |         |                       | 22.2              |               | 0.256                   | 0.0569           | 0.0285          | 2.78    | 16.9    |        |
| O                      | Incinerator                                | Process gas  | 1.51                 |                       |                  |         |                       | 4.12              |               |                         |                  |                 |         |         |        |
| O                      | Incinerator                                | Process gas  | 1.31                 |                       |                  |         |                       | 3.56              |               |                         |                  |                 |         |         |        |
| UT                     | Boiler                                     | Process gas  | 3.77                 |                       |                  | 170     |                       | 14.1              | 0.244         | 11.9                    | 33.7             | 1.83            | 1.7     | 917     |        |
| UT                     | Boiler                                     | Process gas  | 3.63                 |                       |                  | 164     |                       | 13.6              | 0.234         | 11.5                    | 32.5             | 1.76            | 1.64    | 883     |        |
| UT                     | Flare                                      | Process gas  | 0.00333              |                       | 0.0072           |         | 0.0020                | 0.0792            |               | 0.0021                  | 0.00015          | 0.0165          | 0.00292 |         |        |
| UT                     | Flare                                      | Process gas  | 0.00333              |                       | 0.0072           |         | 0.0020                | 0.0792            |               | 0.0021                  | 0.00015          | 0.3             | 0.00292 |         |        |
| D                      | CO boiler                                  | Process gas  | 1.21                 |                       |                  |         | 29.6                  | 2.07              | 475           | 369                     | 9.8              | 302             | 40.7    |         |        |
| D                      | CO boiler                                  | Process gas  | 1.35                 |                       |                  |         | 32.9                  | 2.3               | 527           | 409                     | 10.9             | 335             | 45.2    |         |        |
| I                      | Process heater                             | Process gas  | 0.444                |                       | 0.0145           |         | 0.0041                | 10.6              |               | 0.281                   | 0.0207           | 0.0331          | 0.391   | 2.76    | 1.8    |
| H                      | Process heater                             | Process gas  | 1.33                 |                       |                  |         |                       | 3.62              |               | 0.0418                  | 0.00929          | 0.0046          | 0.371   | 1.8     | 1.8    |
| H                      | IC engine                                  | Process gas  | 1.35                 |                       |                  | 4.94    |                       | 36.4              |               |                         |                  |                 |         |         |        |
| H                      | IC engine                                  | Process gas  | 1.35                 |                       |                  | 4.94    |                       | 36.4              |               |                         |                  |                 |         |         |        |
| H                      | Process heater                             | Process gas  | 0.331                |                       | 0.0108           |         | 0.0030                | 7.89              |               | 0.21                    | 0.0154           | 0.0247          | 0.291   |         |        |
| H                      | Process heater                             | Process gas  | 0.213                |                       | 0.0069           |         | 0.0019                | 5.07              |               | 0.135                   | 0.0099           | 0.0158          | 0.187   |         |        |
| H                      | Process heater                             | Process gas  | 0.446                |                       | 0.0145           |         | 0.0041                | 10.6              |               | 0.282                   | 0.0208           | 0.0332          | 0.392   |         |        |
| E                      | Process heater                             | Process gas  | 1.54                 |                       | 0.0502           |         | 0.0144                | 36.7              |               | 0.976                   | 0.0717           | 0.115           | 1.36    |         |        |
| E                      | Process heater                             | Process gas  | 1.8                  |                       | 0.0586           |         | 0.0168                | 42.9              |               | 1.14                    | 0.0838           | 0.134           | 1.58    |         |        |
| H                      | Process heater                             | Process gas  | 0.578                |                       | 0.0188           |         | 0.0053                | 13.8              |               | 0.18                    | 0.0269           | 0.043           | 0.508   |         |        |
| H                      | Process heater                             | Process gas  | 0.284                |                       | 0.0092           |         | 0.0026                | 6.77              |               | 2                       | 0.0132           | 0.0217          | 0.25    |         |        |
| UT                     | Boiler                                     | Process gas  | 3.46                 |                       |                  |         |                       | 26.8              | 0.546         |                         | 74.5             | 5.64            | 5.46    | 597     |        |
| UT                     | Boiler                                     | Fuel oil     |                      |                       |                  |         |                       |                   |               | 1.59                    |                  |                 |         |         |        |
| UT                     | Boiler                                     | Process gas  | 2.75                 |                       |                  |         |                       | 21.3              | 0.435         |                         | 59.3             | 4.49            | 4.35    | 476     |        |
| UT                     | IC engine                                  | Process gas  | 0.486                |                       |                  | 1.78    |                       | 13.1              |               |                         |                  |                 |         | 0.648   | 0.648  |
| UT                     | IC engine                                  | Process gas  | 0.486                |                       |                  | 1.78    |                       | 13.1              |               |                         |                  |                 |         | 0.648   | 0.648  |
| UT                     | Flare                                      | Process gas  | 0.00998              |                       | 0.0217           |         | 0.0061                | 0.238             |               | 0.00631                 | 0.00046          | 0.0495          | 0.00877 |         |        |
| UT                     | Flare                                      | Process gas  | 0.00998              |                       | 0.0217           |         | 0.0061                | 0.238             |               | 0.00631                 | 0.00046          | 0.0495          | 0.00877 |         |        |
| N                      | Coke handling                              |              |                      |                       |                  |         |                       |                   |               |                         |                  | 51.7            |         |         |        |
| Total emissions by HAP |  |              |                      | 162                   | 0.518            | 347     | 62.6                  | 864               | 1,000         | 818                     | 222              | 704             | 147     | 3,140   | 4.9    |

\*Refinery process code:

A - Crude unit

B - Vacuum distillation

C - Thermal operations

D - Catalytic Cracking

E - Catalytic Reforming

F - Catalytic Hydrocracking

G - Catalytic Hydrorefining

H - Catalytic hydrotreating

I - Alkylation/polymerization

J - Aromatics/isomerization

K - Lubes

L - Asphalt

M - Hydrogen

N - Coke

O - Sulfur

UT - Utilities

TABLE 2-8. REPORTED HAP EMISSIONS BY PROCESS VENT AND COMBUSTION SOURCE - REFINERY J

| Refinery process | Process vent/<br>combustion source type | Fuel type    | Fuel usage/<br>or heat input/yr** | HAP Emissions (lb/yr) |         |                   |                         |                  |                  |                 |        |         |        |
|------------------|---|--------------|-----------------------------------|-----------------------|---------|-------------------|-------------------------|------------------|------------------|-----------------|--------|---------|--------|
|                  |   |              |                                   | Acetal-<br>dehyde     | Benzene | Formal-<br>dehyde | Man-<br>genese<br>comp. | Mercury<br>comp. | Naph-<br>thalene | Nickel<br>comp. | Phenol | Toluene | Xylene |
| B                | Boiler                                  | Refinery gas |                                   |                       |         | 5.7               |                         | 0.1              | 4.5              |                 | 0.9    |         |        |
| UT               | Boiler                                  | Refinery gas |                                   | 2.2                   |         | 2.2               | 0.1                     | 0.5              | 0.6              | 0.2             | 0.1    |         |        |
| UT               | Boiler                                  | Refinery gas |                                   | 3.2                   |         | 3.2               | 0.1                     | 0.7              | 0.9              | 0.3             | 0.1    |         |        |
| UT               | Boiler                                  | Refinery gas |                                   | 1.6                   |         | 1.6               | 0.1                     | 0.4              | 0.4              | 0.1             | 0.1    |         |        |
| A                | Process heater                          | Refinery gas |                                   | 43.4                  |         | 39.4              |                         | 0.5              | 31.5             |                 | 6.1    |         |        |
| A                | Process heater                          | Refinery gas |                                   | 8.8                   |         | 8                 |                         | 0.1              |                  |                 | 1.2    |         |        |
| A                | Process heater                          | Refinery gas |                                   | 35.7                  |         | 32.4              |                         | 0.4              | 25.9             |                 | 5      |         |        |
| B                | Process heater                          | Refinery gas |                                   | 13                    |         | 11.8              |                         | 0.1              | 9.4              |                 | 1.8    |         |        |
| B                | Process heater                          | Refinery gas |                                   | 16.1                  |         | 14.6              |                         | 0.2              | 11.7             |                 | 2.3    |         |        |
| B                | Process heater                          | Refinery gas |                                   | 4.4                   |         | 4                 |                         |                  | 3.2              |                 | 0.6    |         |        |
| E                | Process heater                          | Refinery gas |                                   | 2.6                   |         | 2.3               |                         |                  | 1.9              |                 | 0.4    |         |        |
| E                | Process heater                          | Refinery gas |                                   | 29.2                  |         | 26.6              |                         | 0.3              | 21.2             |                 | 4.1    |         |        |
| E                | Process heater                          | Refinery gas |                                   | 40.3                  |         | 36.6              |                         | 0.5              | 29.2             |                 | 5.7    |         |        |
| E                | Process heater                          | Refinery gas |                                   | 4.6                   |         | 4.2               |                         | 0.1              | 3.4              |                 | 0.7    |         |        |
| D                | Process heater                          | Refinery gas |                                   | 0.1                   |         |                   |                         |                  |                  |                 |        |         |        |
| D                | Process heater                          | Refinery gas |                                   | 0.2                   |         | 0.2               |                         |                  | 0.2              |                 |        |         |        |
| H                | Process heater                          | Refinery gas |                                   | 14.6                  |         | 13.3              |                         | 0.2              | 10.6             |                 | 2      |         |        |
| G                | Process heater                          | Refinery gas |                                   | 3                     |         | 2.7               |                         |                  | 2.2              |                 | 0.4    |         |        |
| C                | Process heater                          | Refinery gas |                                   | 23.7                  |         | 21.6              |                         | 0.3              | 17.2             |                 | 3.4    |         |        |
| C                | Process heater                          | Refinery gas |                                   | 23.7                  |         | 21.6              |                         | 0.3              | 1.2              |                 | 0.2    |         |        |
| C                | Process heater                          | Refinery gas |                                   | 1.2                   |         | 1.1               |                         |                  | 0.9              |                 | 0.2    |         |        |
| H                | Process heater                          | Refinery gas |                                   | 1.2                   |         | 1.1               |                         |                  | 0.9              |                 | 0.2    |         |        |
| H                | Process heater                          | Refinery gas |                                   | 15.9                  |         | 14.5              |                         | 0.2              | 11.5             |                 | 2.2    |         |        |
| H                | Process heater                          | Refinery gas |                                   | 5.6                   |         | 5.1               |                         |                  | 4.1              |                 | 0.8    |         |        |
| H                | Process heater                          | Refinery gas |                                   | 5.8                   |         | 5.2               |                         |                  | 4.2              |                 | 0.8    |         |        |
| F                | Process heater                          | Refinery gas |                                   | 3.1                   |         | 2.8               |                         |                  | 2.2              |                 | 0.4    |         |        |
| F                | Process heater                          | Refinery gas |                                   | 2.9                   |         | 2.6               |                         |                  | 2.1              |                 | 0.4    |         |        |
| F                | Process heater                          | Refinery gas |                                   | 2.4                   |         | 2.2               |                         |                  | 1.8              |                 | 0.3    |         |        |
| F                | Process heater                          | Refinery gas |                                   | 3.1                   |         | 2.8               |                         |                  | 2.2              |                 | 0.4    |         |        |
| F                | Process heater                          | Refinery gas |                                   | 3.1                   |         | 2.8               |                         |                  | 2.3              |                 | 0.4    |         |        |
| F                | Process heater                          | Refinery gas |                                   | 3.2                   |         | 2.9               |                         |                  | 2.4              |                 | 0.5    |         |        |
| F                | Process heater                          | Refinery gas |                                   | 20.4                  |         | 18.5              |                         | 0.2              | 14.8             |                 | 2.9    |         |        |
| M                | Process heater                          | Refinery gas |                                   | 126                   |         | 42.9              |                         | 1.3              | 26.3             |                 | 2.2    |         |        |
| UT               | Boiler                                  | Fuel oil     |                                   |                       |         | 66.4              | 76.8                    |                  |                  |                 |        |         |        |
| D                | CO boiler                               | Gas oil      |                                   | 537                   |         | 562               | 688                     |                  |                  | 171             | 491    |         |        |
| C                | Boiler                                  | Fuel oil     |                                   |                       |         |                   |                         |                  |                  |                 |        |         |        |
| F                | Process heater                          | Refinery gas |                                   | 1                     |         | 19.2              |                         | 0.2              | 15.3             |                 | 3      |         |        |

(continued)

TABLE 2-8. (Continued)

| Refinery process*      | Process vent/<br>combustion<br>source type | Fuel<br>type      | Fuel usage/yr<br>or<br>heat input/yr** | HAP Emissions (lb/yr) |         |                   |                         |                  |                  |                 |        |         |        |
|------------------------|--|-------------------|--|-----------------------|---------|-------------------|-------------------------|------------------|------------------|-----------------|--------|---------|--------|
|                        |  |                   |  | Acetal-<br>dehyde     | Benzene | Formal-<br>dehyde | Man-<br>ganese<br>comp. | Mercury<br>comp. | Naph-<br>thalene | Nickel<br>comp. | Phenol | Toluene | Xylene |
| UT                     | IC engine                                  | Natural gas       |  | 0.3                   | 1.2     | 8.7               |                         |                  | 0.00012          |                 |        | 0.4     | 0.4    |
| UT                     | IC engine                                  | Natural gas       |  | 0.3                   | 1.2     | 8.7               |                         |                  | 0.00012          |                 |        | 0.4     | 0.4    |
| UT                     | IC engine                                  | Natural gas       |  | 0.3                   | 1.2     | 8.7               |                         |                  | 0.00012          |                 |        | 0.4     | 0.4    |
| UT                     | IC engine                                  | Natural gas       |  | 1.5                   | 5.4     | 39.5              |                         |                  | 0.00055          |                 |        | 2       | 2      |
| UT                     | IC engine                                  | Natural gas       |  | 1.5                   | 5.4     | 39.5              |                         |                  | 0.00055          |                 |        | 2       | 2      |
| UT                     | IC engine                                  | Natural gas       |  | 1.5                   | 5.4     | 39.5              |                         |                  | 0.00055          |                 |        | 2       | 2      |
| UT                     | IC engine                                  | Natural gas       |  | 1.5                   | 5.4     | 39.5              |                         |                  | 0.00055          |                 |        | 2       | 2      |
| UT                     | IC engine                                  | Natural gas       |  | 1.5                   | 5.4     | 39.5              |                         |                  | 0.00055          |                 |        | 2       | 2      |
| UT                     | IC engine                                  | Natural gas       |  | 1.5                   | 5.4     | 39.5              |                         |                  | 0.00055          |                 |        | 2       | 2      |
| UT                     | Turbine                                    | Natural gas       |  | 0.6                   | 2.1     | 15.6              |                         |                  | 0.00055          |                 |        | 2       | 2      |
| O                      | SRU incinerator                            | Refinery make gas |  |                       | 0.3     |                   |                         |                  | 0.014            |                 |        | 0.8     | 0.8    |
| Total emissions by HAP |  |                   |  | 1,010                 | 38.4    | 1,286             | 765                     | 6.6              | 267              | 172             | 541    | 14      | 14     |

\*Refinery process code:

A - Crude unit  
 B - Vacuum distillation  
 C - Thermal operations  
 D - Catalytic cracking  
 E - Catalytic reforming  
 F - Catalytic hydrocracking  
 G - Catalytic hydrotreating  
 H - Catalytic hydrotreating  
 I - Alkylation/polymerization  
 J - Aromatics/isomerization  
 K - Lubes  
 L - Asphalt  
 M - Hydrogen  
 N - Coke  
 O - Sulfur  
 UT - Utilities

\*\* Confidential for this refinery.

TABLE 2-9. REPORTED HAP EMISSIONS BY PROCESS VENT AND COMBUSTION SOURCE - REFINERY K

| Refinery process* | Process vent/<br>combustion source type | Fuel type   | Heat input/<br>yr | HAP Emissions (lb/yr) |         |         |         |              |       |            |         |             |        |
|-------------------|---|-------------|-------------------|-----------------------|---------|---------|---------|--------------|-------|------------|---------|-------------|--------|
|                   |   |             |                   | Acetaldehyde          | Arsenic | Benzene | Cadmium | Formaldehyde | Lead  | Man-ganese | Mercury | Naphthalene | Nickel |
|                   |   |             |                   | comp.                 | comp.   | comp.   | comp.   | comp.        | comp. | comp.      | comp.   | comp.       | comp.  |
| A                 | Process heater                          | Process gas | 23.4              | 0.0046                | 0.0164  |         |         | 63.5         |       | 0.734      | 0.163   | 13          | 0.0816 |
| B                 | Process heater                          | Process gas | 12.2              |                       |         |         |         | 33.1         |       | 0.382      | 0.085   | 6.76        | 0.0425 |
| B                 | Process heater                          | Process gas | 0.503             |                       |         |         |         | 12           |       | 0.318      | 0.0234  | 0.731       | 0.0375 |
| A                 | Process heater                          | Process gas | 37.8              |                       |         |         |         | 103          |       | 1.19       | 0.264   | 21          | 0.132  |
| A                 | Process heater                          | Process gas | 20.7              |                       |         |         |         | 56.1         |       | 0.648      | 0.144   | 11.4        | 0.072  |
| A                 | Process heater                          | Process gas | 20.7              |                       |         |         |         | 56.1         |       | 0.648      | 0.144   | 11.4        | 0.072  |
| C                 | Process heater                          | Process gas | 1.19              |                       |         |         |         | 28.3         |       | 0.751      | 0.0552  | 1.72        | 0.0884 |
| C                 | Process heater                          | Process gas | 1.19              |                       |         |         |         | 28.3         |       | 0.751      | 0.0552  | 1.72        | 0.0884 |
| H/E               | Process heater                          | Process gas | 1.16              |                       |         |         |         | 27.6         |       | 0.733      | 0.0539  | 1.68        | 0.0863 |
| H/E               | Process heater                          | Process gas | 1.16              |                       |         |         |         | 27.6         |       | 0.733      | 0.0539  | 1.68        | 0.0863 |
| H/E               | Process heater                          | Process gas | 0.275             |                       |         |         |         | 6.54         |       | 0.174      | 0.0128  | 0.398       | 0.0204 |
| H/E               | Process heater                          | Process gas | 3.34              |                       |         |         |         | 79.5         |       | 2.11       | 0.155   | 4.85        | 0.249  |
| H/E               | Process heater                          | Process gas | 0.61              |                       |         |         |         | 14.5         |       | 0.386      | 0.0284  | 0.886       | 0.0454 |
| H                 | Process heater                          | Process gas | 0.208             |                       |         |         |         | 4.96         |       | 0.132      | 0.00969 | 0.302       | 0.0155 |
| H                 | Process heater                          | Process gas | 0.476             |                       |         |         |         | 11.3         |       | 0.301      | 0.0221  | 0.691       | 0.0354 |
| H                 | Process heater                          | Process gas | 0.268             |                       |         |         |         | 6.38         |       | 0.169      | 0.0125  | 0.389       | 0.0199 |
| H                 | Process heater                          | Process gas | 0.358             |                       |         |         |         | 8.52         |       | 0.226      | 0.0166  | 0.519       | 0.0266 |
| H                 | Process heater                          | Process gas | 1.32              |                       |         |         |         | 31.4         |       | 0.834      | 0.0613  | 1.91        | 0.0981 |
| H                 | Process heater                          | Process gas | 0.377             |                       |         |         |         | 8.97         |       | 0.238      | 0.0175  | 0.547       | 0.028  |
| H/E               | Process heater                          | Process gas | 0.56              |                       |         |         |         | 13.3         |       | 0.355      | 0.0261  | 0.813       | 0.0417 |
| H/E               | Process heater                          | Process gas | 0.506             |                       |         |         |         | 12.1         |       | 0.32       | 0.0235  | 0.735       | 0.0377 |
| H/E               | Process heater                          | Process gas | 5.48              |                       |         |         |         | 130          |       | 3.47       | 0.255   | 7.95        | 0.408  |
| H/E               | Process heater                          | Process gas | 0.615             |                       |         |         |         | 14.6         |       | 0.389      | 0.0286  | 0.892       | 0.0457 |
| H/E               | Process heater                          | Process gas | 0.579             |                       |         |         |         | 13.8         |       | 0.366      | 0.0269  | 0.84        | 0.0431 |
| H/E               | Process heater                          | Process gas | 0.145             |                       |         |         |         | 3.44         |       | 0.0915     | 0.00673 | 0.21        | 0.0108 |
| I                 | Process heater                          | Process gas | 0.292             |                       |         |         |         | 6.94         |       | 0.184      | 0.0136  | 0.423       | 0.0217 |
| F                 | Process heater                          | Process gas | 5                 |                       |         |         |         | 119          |       | 3.17       | 0.233   | 7.26        | 0.372  |
| F                 | Process heater                          | Process gas | 0.497             |                       |         |         |         | 11.8         |       | 0.314      | 0.0231  | 0.721       | 0.037  |
| F                 | Process heater                          | Process gas | 2.61              |                       |         |         |         | 62           |       | 1.65       | 0.121   | 3.78        | 0.194  |
| F                 | Process heater                          | Process gas | 0.634             |                       |         |         |         | 15.1         |       | 0.401      | 0.0295  | 0.92        | 0.0472 |
| F                 | Process heater                          | Process gas | 1.51              |                       |         |         |         | 35.9         |       | 0.954      | 0.0702  | 2.19        | 0.112  |
| D                 | Process heater                          | Process gas | 0.768             |                       |         |         |         | 18.3         |       | 0.486      | 0.0357  | 1.12        | 0.0572 |
| D                 | Process heater                          | Process gas | 0.588             |                       |         |         |         | 14           |       | 0.372      | 0.0273  | 0.853       | 0.0437 |
| D                 | Process heater                          | Process gas | 0.437             |                       |         |         |         | 10.4         |       | 0.276      | 0.0203  | 0.634       | 0.0325 |
| D                 | Process heater                          | Process gas | 0.151             |                       |         |         |         | 3.59         |       | 0.0953     | 0.00701 | 0.219       | 0.0112 |
| UT                | Process heater                          | Process gas | 2.34              |                       |         | 126     |         | 6.83         | 0.12  | 2.4        | 0.479   | 1.44        | 0.599  |
| UT                | Process heater                          | Process gas | 2.34              |                       |         | 126     |         | 6.83         | 0.12  | 2.4        | 0.479   | 1.44        | 0.599  |
| UT                | Process heater                          | Process gas | 3.87              |                       |         | 209     |         | 11.3         | 0.199 | 3.97       | 0.795   | 2.38        | 0.993  |
| UT                | Process heater                          | Process gas | 3.43              |                       |         |         |         | 26.5         | 0.542 | 1.99       | 73.8    | 5.06        | 5.6    |

(continued)

TABLE 2-9. (Continued)

| Refinery process*      | Process vent/<br>source type | Fuel<br>type | Heat<br>input/<br>yr | HAP Emissions (lb/yr)   |                  |                  |                       |                            |               |                         |                  |                           |                 |        |         |
|------------------------|------------------------------|--------------|----------------------|-------------------------|------------------|------------------|-----------------------|----------------------------|---------------|-------------------------|------------------|---------------------------|-----------------|--------|---------|
|                        |                              |              |                      | Acetal-<br>dehyde comp. | Arsenic<br>comp. | Benzene<br>comp. | Cad-<br>mium<br>comp. | Formal-<br>dehyde<br>comp. | Lead<br>comp. | Man-<br>ganese<br>comp. | Mercury<br>comp. | Naph-<br>thalene<br>comp. | Nickel<br>comp. | Phenol | Toluene |
| UT                     | Process heater               | Process gas  |                      | 3.75                    |                  | 202              |                       | 11                         | 0.192         | 3.85                    | 0.769            | 2.31                      | 0.962           | 0.192  | 703     |
| C                      | IC engine                    | Process gas  |                      |                         |                  | 0.0121           |                       |                            |               |                         |                  |                           |                 |        |         |
| UT                     | Flare                        | Process gas  |                      | 0.215                   | 0.00701          |                  | 0.002                 | 5.13                       |               | 17.2                    | 0.01             | 0.312                     | 0.016           | 0.189  |         |
| UT                     | Flare                        | Process gas  |                      | 0.215                   | 0.00701          |                  | 0.002                 | 5.13                       |               | 17.2                    | 0.01             | 0.312                     | 0.016           | 0.189  |         |
| UT                     | Flare                        | Process gas  |                      | 0.0807                  | 0.00263          |                  | 0.0007                | 1.92                       |               | 6.45                    | 0.00376          | 0.117                     | 0.00601         | 0.071  |         |
| O                      | SRU                          |              |                      | 0.135                   |                  |                  |                       | 21.1                       |               |                         |                  |                           |                 |        |         |
| O                      | SRU                          |              |                      | 0.096                   |                  |                  |                       | 15.1                       |               |                         |                  |                           |                 |        |         |
| D                      | FCCU                         |              |                      |                         | 2.81             |                  |                       |                            |               | 3.38                    | 0.844            | 21.7                      | 4.64            | 505    |         |
| Total emissions by HAP |                              |              |                      | 189                     | 3.89             | 663              | 0.31                  | 1,270                      | 1.17          | 84                      | 79.7             | 160                       | 16.4            | 579    | 3,198   |

\*Refinery process code:

A - Crude unit  
 B - Vacuum distillation  
 C - Thermal operations  
 D - Catalytic cracking  
 E - Catalytic reforming  
 F - Catalytic hydrocracking  
 G - Catalytic hydrotreating  
 H - Catalytic hydrotreating  
 I - Alkylation/polymerization  
 J - Aromatics/isomerization  
 K - Lubes  
 L - Asphalt  
 M - Hydrogen  
 N - Coke  
 O - Sulfur  
 UT - Utilities

TABLE 2-10. REPORTED HAP EMISSIONS BY PROCESS VENT AND COMBUSTION SOURCE

| Emission source       | HAP Emissions (lb/yr) |                  |         |                         |                       |                        |        |                   |               |                         |                  |                           |                 |                 |                        |         |        |
|-----------------------|-----------------------|------------------|---------|-------------------------|-----------------------|------------------------|--------|-------------------|---------------|-------------------------|------------------|---------------------------|-----------------|-----------------|------------------------|---------|--------|
|                       | Acetal-<br>dehyde     | Arsenic<br>comp. | Benzene | Beryl-<br>lium<br>comp. | Cad-<br>mium<br>comp. | Chro-<br>mium<br>comp. | Cresol | Formal-<br>dehyde | Lead<br>comp. | Man-<br>ganese<br>comp. | Mercury<br>comp. | Naph-<br>thalene<br>comp. | Nickel<br>comp. | Phenol<br>comp. | Selen-<br>ium<br>comp. | Toluene | Xylene |
| Combustion sources    |                       |                  |         |                         |                       |                        |        |                   |               |                         |                  |                           |                 |                 |                        |         |        |
| Process heaters       | 1,420                 | 4.23             | 162     | 0.6                     | 2.64                  | 6.91                   |        | 4,860             | 3.8           | 76.1                    | 15.3             | 683                       | 177             | 228             |                        | 4,530   | 4      |
| Boilers               | 75.8                  |                  | 1,040   |                         |                       | 1.31                   |        | 721               | 2.63          | 807                     | 284              | 32.5                      | 211             | 28.9            |                        | 10,700  | 4      |
| IC engines            | 13.6                  |                  | 212     |                         |                       |                        |        | 21,200            |               |                         |                  | 0.0036                    |                 | 0.003           |                        | 18.1    | 18.1   |
| Turbines              | 21.9                  |                  | 31.6    |                         |                       | 0.97                   |        | 465               |               | 1.72                    | 3.58             | 10.6                      | 10.3            | 5.4             |                        | 3,150   | 0.8    |
| Flares                | 41.3                  | 0.0744           | 0.875   |                         | 0.0213                | 0.118                  |        | 198               |               | 42.5                    | 0.11             | 43.5                      | 0.454           | 11              |                        | 641     |        |
| Incinerators          | 2.82                  |                  |         |                         |                       |                        |        | 7.68              |               |                         |                  |                           |                 |                 |                        |         |        |
| Process vents         |                       |                  |         |                         |                       |                        |        |                   |               |                         |                  |                           |                 |                 |                        |         |        |
| FCCU w/o CO boiler    |                       | 2.81             |         |                         |                       |                        |        |                   |               | 3.38                    | 0.844            | 21.7                      | 4.64            | 505             |                        |         |        |
| FCCU w/ CO boiler     | 540                   | 18.2             |         | 18.2                    | 162                   | 9.6                    | 1.02   | 566               | 1,100         | 1,310                   | 21.2             |                           | 1,050           | 578             | 280                    |         |        |
| Sulfur recovery units | 0.231                 |                  | 0.3     |                         |                       |                        |        | 36.1              |               |                         |                  |                           |                 |                 |                        |         |        |
| Coke                  |                       |                  |         |                         |                       |                        |        |                   |               |                         |                  |                           |                 |                 |                        |         |        |
| Total                 | 2,120                 | 25.3             | 1,440   | 18.8                    | 165                   | 18.9                   | 1.02   | 28,100            | 1,110         | 2,240                   | 325              | 792                       | 1,510           | 1,360           | 280                    | 19,000  | 26.9   |
| % of total emissions  | 3.62                  | 0.04             | 2.46    | 0.03                    | 0.28                  | 0.03                   | 0.002  | 48.00             | 1.90          | 3.82                    | 0.55             | 1.35                      | 2.57            | 2.31            | 0.48                   | 32.40   | 0.05   |



TABLE 2-11. (Continued)

| Emission sources    | HAP             | Crude | Vacuum dist. | Thermal operations | HAP Emission Factors<br>(lb/yr per 1000 Bbl/sd refinery process charge capacity) |               |                    |                    |                       | (lb/yr per t/d) |
|---------------------|-----------------|-------|--------------|--------------------|--|---------------|--------------------|--------------------|-----------------------|-----------------|
|                     |                 |       |              |                    | Cat cracking   | Cat reforming | Cat hydro cracking | Cat hydro refining | Alky- isomer- ization |                 |
| Boilers (continued) |                 |       |              |                    |  |               |                    |                    |                       |                 |
| Fuel oil            | Manganese comp. |       |              | 14.9               |  |               |                    |                    |                       |                 |
|                     | Nickel comp.    |       |              | 3.7                |  |               |                    |                    |                       |                 |
|                     | Total HAP       |       |              | 18.6               |  |               |                    |                    |                       |                 |
| IC engines          |                 |       |              |                    |  |               |                    |                    |                       |                 |
| Process gas         | Acetaldehyde    |       |              |                    |  |               |                    |                    |                       |                 |
|                     | Benzene         |       |              | 0.000604           |  |               |                    | 0.0287             |                       |                 |
|                     | Formaldehyde    |       |              |                    |  |               |                    | 0.105              |                       |                 |
|                     | Toluene         |       |              |                    |  |               |                    | 0.776              |                       |                 |
|                     | Xylene          |       |              |                    |  |               |                    | 0.0383             |                       |                 |
|                     | Total HAP       |       |              | 0.000604           |  |               |                    | 0.987              |                       |                 |
| Turbines            |                 |       |              |                    |  |               |                    |                    |                       |                 |
| Process gas         | Acetaldehyde    |       |              |                    |  |               |                    |                    |                       |                 |
|                     | Benzene         |       |              |                    | 0.185  |               | 0.138              |                    | 0.189                 |                 |
|                     | Chromium comp.  |       |              |                    | 0.233  |               | 0.228              |                    | 0.331                 |                 |
|                     | Formaldehyde    |       |              |                    | 0.0084   |               | 0.00625            |                    | 0.00875               |                 |
|                     | Manganese comp. |       |              |                    | 0.516  |               | 0.385              |                    | 0.526                 |                 |
|                     | Mercury comp.   |       |              |                    | 0.0149   |               | 0.0113             |                    | 0.015                 |                 |
|                     | Naphthalene     |       |              |                    | 0.0311   |               | 0.0231             |                    | 0.0319                |                 |
|                     | Nickel comp.    |       |              |                    | 0.0916   |               | 0.0684             |                    | 0.0938                |                 |
|                     | Phenol          |       |              |                    | 0.0891   |               | 0.0666             |                    | 0.0906                |                 |
|                     | Toluene         |       |              |                    | 0.0468   |               | 0.035              |                    | 0.0481                |                 |
|                     | Total HAP       |       |              |                    | 27.3   |               | 20.4               |                    | 27.9                  |                 |
|                     |                 |       |              |                    | 28.6   |               | 21.4               |                    | 29.2                  |                 |
| Incinerators        |                 |       |              |                    |  |               |                    |                    |                       |                 |
| Process gas         | Acetaldehyde    |       |              |                    |  |               |                    |                    |                       |                 |
|                     | Formaldehyde    |       |              |                    |  |               |                    |                    |                       |                 |
|                     | Total HAP       |       |              |                    |  |               |                    |                    |                       |                 |
| FCCU w/o CO boiler  |                 |       |              |                    |  |               |                    |                    |                       |                 |
|                     | Arsenic comp.   |       |              |                    | 0.0599   |               |                    |                    |                       | 0.0141          |
|                     | Manganese comp. |       |              |                    | 0.0718   |               |                    |                    |                       | 0.0384          |
|                     | Mercury comp.   |       |              |                    | 0.018  |               |                    |                    |                       | 0.0525          |
|                     | Naphthalene     |       |              |                    | 0.461  |               |                    |                    |                       |                 |
|                     | Nickel comp.    |       |              |                    | 0.0987   |               |                    |                    |                       |                 |
|                     | Phenol          |       |              |                    | 10.7   |               |                    |                    |                       |                 |
|                     | Total HAP       |       |              |                    | 11.5   |               |                    |                    |                       |                 |

Continued

(continued)

TABLE 2-11. (Continued)

| Emission sources      | HAP             | Crude | Vacuum dist. | Thermal operations | Cat cracking | Cat reforming | Cat hydro cracking | Cat hydro treating | HAP Emission Factors                                     |           |                      | (lb/yr per t/d) |
|-----------------------|-----------------|-------|--------------|--------------------|--------------|---------------|--------------------|--------------------|--|-----------|----------------------|-----------------|
|                       |                 |       |              |                    |              |               |                    |                    | (lb/yr per 1000 Bbl/sd refinery process charge capacity) | Aromatics | Alky- isomer-ization | (lb/yr per t/d) |
|                       | Acetaldehyde    |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       | Cadmium comp.   |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       | Formaldehyde    |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       | Lead comp.      |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       | Manganese comp. |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       | Mercury comp.   |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       | Nickel comp.    |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       | Phenol          |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       | Total HAP       |       |              |                    |              |               |                    |                    |  |           |                      |                 |
| Fresh feed            | Benzene         |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       | Formaldehyde    |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       | Total HAP       |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       |                 |       |              |                    |              |               |                    |                    |  |           |                      |                 |
| CO gas                | Arsenic comp.   |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       | Beryllium comp. |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       | Cadmium comp.   |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       | Chromium comp.  |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       | Cresol          |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       | Lead comp.      |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       | Manganese comp. |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       | Nickel comp.    |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       | Phenol          |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       | Selenium comp.  |       |              |                    |              |               |                    |                    |  |           |                      |                 |
| Gas oil               | Total HAP       |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       | Acetaldehyde    |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       | Formaldehyde    |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       | Phenol          |       |              |                    |              |               |                    |                    |  |           |                      |                 |
| Sulfur recovery units | Total HAP       |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       | Acetaldehyde    |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       | Benzene         |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       | Formaldehyde    |       |              |                    |              |               |                    |                    |  |           |                      |                 |
| Coke handling         | Total HAP       |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       | Nickel comp.    |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       |                 |       |              |                    |              |               |                    |                    |  |           |                      |                 |
|                       |                 |       |              |                    |              |               |                    |                    |  |           |                      |                 |

0.00115  
0.0007  
0.183  
0.06

0.020

TABLE 2-12. HAP EMISSION FACTORS (10<sup>-6</sup> lb/MMBtu)

| Emission sources | HAP             | Thermal |              |                    |              |               | Aromatics          |                    |                    |            |               |         |         |          |           |
|------------------|-----------------|---------|--------------|--------------------|--------------|---------------|--------------------|--------------------|--------------------|------------|---------------|---------|---------|----------|-----------|
|                  |                 | Crude   | Vacuum dist. | Thermal operations | Cat cracking | Cat reforming | Cat hydro cracking | Cat hydro refining | Cat hydro treating | Alkylation | Isomerization | Lubes   | Asphalt | Hydrogen | Utilities |
| Process heaters  |                 |         |              |                    |              |               |                    |                    |                    |            |               |         |         |          |           |
| Process Gas      | Acetaldehyde    | 12.6    | 8.1          | 12.1               | 165          | 9.53          | 5.51               | 26.3               | 15.4               |            |               | 9.01    | 12.4    | 23.6     | 1.82      |
|                  | Benzene         | 2.48    |              | 1.39               | 20.4         | 1.52          | 1.02               |                    | 2.91               |            | 2.65          | 1.1     |         | 0.97     | 2.09      |
|                  | Chromium comp.  | 0.0302  | 0.0353       | 0.0155             | 2.43         | 0.063         | 0.0454             |                    | 0.066              |            |               | 0.13    | 0.182   | 0.181    | 0.0268    |
|                  | Formaldehyde    | 27.2    | 12.9         | 57.6               | 604          | 36.8          | 30.6               | 23.7               | 59                 |            | 88.5          | 60.6    | 40      | 19.9     | 80        |
|                  | Manganese comp. | 0.27    | 0.316        | 0.0584             | 28.1         | 0.693         | 0.469              |                    | 0.677              |            |               | 1.19    | 1.63    |          | 0.24      |
|                  | Mercury comp.   | 0.0886  | 0.0822       | 0.142              | 1.7          | 0.105         | 0.0565             |                    | 0.136              |            |               | 0.09    | 0.128   | 0.246    | 0.0188    |
|                  | Naphthalene     | 5.61    | 6.64         | 4.87               | 172          | 8.27          | 5.89               | 19.3               | 11.6               |            |               | 9.44    | 12.9    | 4.92     | 1.9       |
|                  | Phenol          | 1.36    | 1.42         | 1.14               | 42           | 1.84          | 1.31               | 3.51               | 2.49               |            |               | 2.32    | 3.2     | 0.41     | 0.469     |
|                  | Toluene         | 32.8    | 33           | 14.5               | 2,430        | 63.6          | 44.8               |                    | 66.7               |            |               | 124     | 171     | 35.5     | 25.1      |
|                  | Total HAP       | 82.4    | 62.5         | 91.7               | 3,470        | 122           | 89.7               | 72.8               | 159                |            | 89.4          | 208     | 241     | 85.8     | 112       |
| Natural Gas      | Acetaldehyde    | 36,400  | 52,600       |                    |              |               |                    |                    |                    |            |               |         | 300,000 |          |           |
|                  | Benzene         | 182,000 | 211,000      |                    |              |               | 6.07               |                    |                    |            |               |         | 400,000 |          |           |
|                  | Formaldehyde    | 436,000 | 474,000      |                    |              |               | 0.391              |                    |                    |            |               |         |         |          |           |
|                  | Toluene         | 90,900  | 105,000      |                    |              |               |                    |                    |                    |            |               |         |         |          |           |
|                  | Xylene          | 54,500  | 52,600       |                    |              |               |                    |                    |                    |            |               |         |         |          |           |
|                  | Total HAP       | 800,000 | 895,000      |                    |              |               | 6.46               |                    |                    |            |               |         | 700,000 |          |           |
| Fuel oil         | Arsenic comp.   |         |              |                    |              |               |                    |                    | 20.1               |            |               |         |         |          |           |
|                  | Benzene         |         |              |                    |              |               |                    |                    | 121                |            |               |         |         |          |           |
|                  | Beryllium comp. |         |              |                    |              |               |                    |                    | 4.47               |            |               |         |         |          |           |
|                  | Cadmium comp.   |         |              |                    |              |               |                    |                    | 16.4               |            |               |         |         |          |           |
|                  | Formaldehyde    |         |              |                    |              |               |                    |                    | 413                |            |               |         |         |          |           |
|                  | Lead comp.      |         |              |                    |              |               |                    |                    | 28.3               |            |               |         |         |          |           |
|                  | Manganese comp. |         |              |                    |              |               |                    |                    | 26.9               |            |               |         |         |          |           |
|                  | Mercury comp.   |         |              |                    |              |               |                    |                    | 2.98               |            |               |         |         |          |           |
|                  | Nickel comp.    |         |              |                    |              |               |                    |                    | 1,290              |            |               |         |         |          |           |
|                  | Toluene         | 15.3    |              |                    |              |               |                    |                    |                    |            |               |         |         |          |           |
|                  | Total HAP       | 15.3    |              |                    |              |               |                    |                    | 1,920              |            |               |         |         |          |           |
| Boilers          |                 |         |              |                    |              |               |                    |                    |                    |            |               |         |         |          |           |
| Process Gas      | Acetaldehyde    |         |              |                    | 5,850        | 4,220         | 4,220              |                    |                    | 4,220      |               | 4,220   |         |          | 2.7       |
|                  | Benzene         |         |              |                    | 713          | 373           | 2,050              |                    |                    | 2,780      |               | 2,780   |         |          | 0.931     |
|                  | Chromium comp.  |         |              |                    | 262          | 187           | 189                |                    |                    | 196        |               | 196     |         |          | 0.058     |
|                  | Formaldehyde    |         |              |                    | 36,600       | 47,600        | 69,300             |                    |                    | 90,700     |               | 90,700  |         |          | 18.7      |
|                  | Manganese comp. |         |              |                    | 476          | 336           | 346                |                    |                    | 344        |               | 344     |         |          | 0.195     |
|                  | Mercury comp.   |         |              |                    | 987          | 709           | 709                |                    |                    | 704        |               | 704     |         |          | 0.486     |
|                  | Naphthalene     |         |              |                    | 2,900        | 2,090         | 2,090              |                    |                    | 2,090      |               | 2,090   |         |          | 1.21      |
|                  | Nickel comp.    |         |              |                    | 2,820        | 2,030         | 2,030              |                    |                    | 2,030      |               | 2,030   |         |          | 1.08      |
|                  | Phenol          |         |              |                    | 1,470        | 1,060         | 1,070              |                    |                    | 1,060      |               | 1,060   |         |          | 0.57      |
|                  | Toluene         |         |              |                    | 865,000      | 624,000       | 624,000            |                    |                    | 624,000    |               | 624,000 |         |          | 251       |
|                  | Total HAP       |         |              |                    | 917,000      | 683,000       | 706,000            |                    |                    | 728,000    |               | 728,000 |         |          | 277       |
| Natural Gas      | Acetaldehyde    |         |              |                    |              |               |                    |                    |                    |            |               |         |         |          | 37,000    |
|                  | Benzene         |         |              |                    |              |               |                    |                    |                    |            |               |         |         |          | 185,000   |
|                  | Formaldehyde    |         |              |                    |              |               |                    |                    |                    |            |               |         |         |          | 435,000   |
|                  | Toluene         |         |              |                    |              |               |                    |                    |                    |            |               |         |         |          | 111,000   |
|                  | Xylene          |         |              |                    |              |               |                    |                    |                    |            |               |         |         |          | 37,000    |
|                  | Total HAP       |         |              |                    |              |               |                    |                    |                    |            |               |         |         |          | 806,000   |

(continued)

(continued)

TABLE 2-12. (Continued)

| Emission sources | HAP             | Crude | Vacuum dist. | Thermal operations | Cat cracking reforming | Cat hydro cracking | Cat hydro refining | Cat hdro treating | Alky-poly | Aromatics isomer-ization | Lubes Asphalt Hydrogen Utilities |
|------------------|-----------------|-------|--------------|--------------------|------------------------|--------------------|--------------------|-------------------|-----------|--------------------------|----------------------------------|
| Fuel oil         | Benzene         |       |              |                    |                        |                    |                    |                   |           |                          | 36.2                             |
|                  | Formaldehyde    |       |              |                    |                        |                    |                    |                   |           |                          | 1,200                            |
|                  | Manganese comp. |       |              | 2,820,000          |                        |                    |                    |                   |           |                          | 1,390                            |
|                  | Nickel comp.    |       |              | 699,000            |                        |                    |                    |                   |           |                          |                                  |
|                  | Toluene         |       |              |                    |                        |                    |                    |                   |           |                          | 18.1                             |
|                  | Total HAP       |       |              | 3,520,000          |                        |                    |                    |                   |           |                          | ,2,650                           |
| IC Engines       |                 |       |              |                    |                        |                    |                    |                   |           |                          |                                  |
| Natural Gas      | Acetaldehyde    |       |              |                    |                        |                    |                    |                   |           |                          | 27.4                             |
|                  | Benzene         |       |              |                    |                        |                    |                    |                   |           |                          | 550                              |
|                  | Formaldehyde    |       |              |                    |                        |                    |                    |                   |           |                          | 59,100                           |
|                  | Naphthalene     |       |              |                    |                        |                    |                    |                   |           |                          | 0.0101                           |
|                  | Toluene         |       |              |                    |                        |                    |                    |                   |           |                          | 36.5                             |
|                  | Xylene          |       |              |                    |                        |                    |                    |                   |           |                          | 36.5                             |
|                  | Total HAP       |       |              |                    |                        |                    |                    |                   |           |                          | 59,700                           |
| Turbines         |                 |       |              |                    |                        |                    |                    |                   |           |                          |                                  |
| Process Gas      | Acetaldehyde    |       |              |                    | 4,220                  | 4,220              |                    |                   | 4,220     |                          |                                  |
|                  | Benzene         |       |              |                    | 5,320                  | 6,970              |                    |                   | 7,410     |                          | 2.31                             |
|                  | Chromium comp.  |       |              |                    | 192                    | 191                |                    |                   | 196       |                          |                                  |
|                  | Formaldehyde    |       |              |                    | 11,800                 | 11,800             |                    |                   | 11,800    |                          |                                  |
|                  | Manganese comp. |       |              |                    | 341                    | 344                |                    |                   | 336       |                          |                                  |
|                  | Mercury comp.   |       |              |                    | 709                    | 707                |                    |                   | 713       |                          |                                  |
|                  | Naphthalene     |       |              |                    | 2,090                  | 2,090              |                    |                   | 2,100     |                          |                                  |
|                  | Nickel comp.    |       |              |                    | 2,030                  | 2,030              |                    |                   | 2,030     |                          |                                  |
|                  | Phenol          |       |              |                    | 1,070                  | 1,070              |                    |                   | 1,080     |                          |                                  |
|                  | Toluene         |       |              |                    | 624,000                | 624,000            |                    |                   | 624,000   |                          | 90.8                             |
|                  | Total HAP       |       |              |                    | 652,000                | 653,000            |                    |                   | 654,000   |                          |                                  |
| Natural Gas      | Acetaldehyde    |       |              |                    |                        |                    |                    |                   |           |                          | 0.623                            |
|                  | Benzene         |       |              |                    |                        |                    |                    |                   |           |                          | 2.18                             |
|                  | Formaldehyde    |       |              |                    |                        |                    |                    |                   |           |                          | 16.2                             |
|                  | Naphthalene     |       |              |                    |                        |                    |                    |                   |           |                          | 0.0145                           |
|                  | Propylene       |       |              |                    |                        |                    |                    |                   |           |                          | 33.7                             |
|                  | Toluene         |       |              |                    |                        |                    |                    |                   |           |                          | 0.831                            |
|                  | Xylene          |       |              |                    |                        |                    |                    |                   |           |                          | 0.831                            |
|                  | Total HAP       |       |              |                    |                        |                    |                    |                   |           |                          | 20.2                             |
| Flares           |                 |       |              |                    |                        |                    |                    |                   |           |                          |                                  |
| Process Gas      | Acetaldehyde    |       |              |                    |                        |                    |                    |                   |           |                          | 145                              |
|                  | Benzene         |       |              |                    |                        |                    |                    |                   |           |                          | 0.41                             |
|                  | Chromium comp.  |       |              |                    |                        |                    |                    |                   |           |                          | 0.421                            |
|                  | Formaldehyde    |       |              |                    |                        |                    |                    |                   |           |                          | 663                              |
|                  | Manganese comp. |       |              |                    |                        |                    |                    |                   |           |                          | 5.75                             |
|                  | Mercury comp.   |       |              |                    |                        |                    |                    |                   |           |                          | 0.303                            |
|                  | Naphthalene     |       |              |                    |                        |                    |                    |                   |           |                          | 153                              |
|                  | Phenol          |       |              |                    |                        |                    |                    |                   |           |                          | 37.6                             |
|                  | Toluene         |       |              |                    |                        |                    |                    |                   |           |                          | 2,280                            |
|                  | Total HAP       |       |              |                    |                        |                    |                    |                   |           |                          | 3,290                            |

(continued)

TABLE 2-12. (Continued)

| Emission sources      | Thermal         |       |              |                    | Aromatics    |               |                    |                                  |
|-----------------------|-----------------|-------|--------------|--------------------|--------------|---------------|--------------------|----------------------------------|
|                       | HAP             | Crude | Vacuum dist. | Thermal operations | Cat cracking | Cat reforming | Cat hydro cracking | Alky- isomer- ization            |
| Natural gas           | Acetaldehyde    |       |              |                    |              |               |                    | Lubes Asphalt Hydrogen Utilities |
|                       | Benzene         |       |              |                    |              |               |                    | 110                              |
|                       | Formaldehyde    |       |              |                    |              |               |                    | 4,200                            |
|                       | Toluene         |       |              |                    |              |               |                    | 90.6                             |
|                       | Total HAP       |       |              |                    |              |               |                    | 7,620                            |
|                       |                 |       |              |                    |              |               |                    | 12,000                           |
| FCCU w/ CO Boiler     |                 |       |              |                    |              |               |                    |                                  |
| Process gas           | Cresol          |       |              |                    |              |               |                    | 0.0101                           |
|                       | Phenol          |       |              |                    |              |               |                    | 0.00968                          |
|                       | Total HAP       |       |              |                    |              |               |                    | 0.0197                           |
| Fuel oil              | Cresol          |       |              |                    |              |               |                    | 0.00713                          |
|                       | Phenol          |       |              |                    |              |               |                    | 0.00671                          |
|                       | Total HAP       |       |              |                    |              |               |                    | 0.0138                           |
| Others (waste liquid) | Arsenic comp.   |       |              |                    |              |               |                    | 99.3                             |
|                       | Beryllium comp. |       |              |                    |              |               |                    | 99.3                             |
|                       | Cadmium comp.   |       |              |                    |              |               |                    | 99.3                             |
|                       | Chromium comp.  |       |              |                    |              |               |                    | 2.48                             |
|                       | Cresol          |       |              |                    |              |               |                    | 0.398                            |
|                       | Lead comp.      |       |              |                    |              |               |                    | 273                              |
|                       | Mercury comp.   |       |              |                    |              |               |                    | 9.93                             |
|                       | Nickel comp.    |       |              |                    |              |               |                    | 905                              |
|                       | Phenol          |       |              |                    |              |               |                    | 0.0567                           |
|                       | Selenium comp.  |       |              |                    |              |               |                    | 323                              |
|                       | Total HAP       |       |              |                    |              |               |                    | 1,810                            |

### 3.0 EQUIPMENT LEAKS

#### 3.1 BACKGROUND INFORMATION

There are many potential sources of hazardous air pollutant (HAP) emissions from leaking equipment in a petroleum refinery. The major sources are valves, pumps, compressors, pressure relief valves, and flanges.<sup>1</sup>

##### 3.1.1 Valves

Valves are one of the most common pieces of equipment in refineries. Several types of valves are used, all of which are activated by a valve stem that opens and closes the throughput pathway. The valve stem requires a seal to isolate the stream flowing through the valve from the atmosphere. The possibility of a leak through this seal makes it a potential source of HAP emissions.<sup>1</sup>

Valves in a refinery are differentiated by the type of stream flowing through them: gas, light liquid, or heavy liquid. Light liquid streams are those with a vapor pressure greater than the vapor pressure of kerosene (0.3 kPa at 20°C). Heavy liquid streams are those with a vapor pressure less than the vapor pressure of kerosene.

##### 3.1.2 Pumps and Compressors

Pumps and compressors are used in petroleum refineries for the movement of liquids and gases, respectively. Pumps are divided into light liquid and heavy liquid stream pumps, while compressors are used for gases only. Pumps and compressors can leak at the contact between the moving shaft and the stationary casing. Seals are required to isolate the liquid or gas flowing through the equipment from the atmosphere. The possibility of a leak through the seal makes pumps and compressors a potential source of HAP emissions.<sup>1</sup>

### 3.1.3 Pressure Relief Valves

Engineering codes require that pressure relief devices be used in applications where the process pressure may exceed the maximum allowable working pressure in the vessel. The most common type of pressure relief device is the pressure relief valve (PRV). Typically, PRV's are designed to open when the process pressure exceeds a set pressure, allowing the release of vapors or liquid until the system pressure is reduced to normal operating levels. When the system pressure returns to normal, the PRV closes down and a seal is formed. The possibility of a leak through the seal or a loose fitting when the PRV is closed makes pressure relief valves a source of VOC emissions.<sup>1</sup>

### 3.1.4 Flanges

Flanges are bolted, gasket-sealed junctions that are used wherever pipe or other equipment, such as reaction vessels, may require isolation or removal. Flanges may become VOC fugitive emission sources when leakage occurs because of improperly chosen gaskets or a poorly assembled flange. The primary cause of flange leakage is due to thermal stress, which results in the deformation of the seal between the flange faces and allows a venue for emissions to occur.<sup>1</sup>

## 3.2 METHOD FOR DEVELOPING HAZARDOUS AIR POLLUTANT EMISSION FACTORS FOR LEAKING EQUIPMENT

Equipment leak emission factors were developed for each equipment type by compiling information from the California refineries. Correlations were generated between speciated HAP emissions and equipment component counts.

### 3.2.1 California Refinery Equipment Leak Database

Ideally, emission factors for leaking petroleum equipment would be based on the composition of streams flowing through each piece of equipment. However, this information was not available from the California Refinery Database.

An alternative emission factor estimation method was developed based on the average emissions of HAP's reported by California refineries complying with the Air Toxics "Hot Spots" Information and Assessment Act of 1987 (AB 2588). For this

approach, the minimum information necessary for calculating emission factors for leaking equipment was:

- the HAP emissions by service type by process unit; and
- the component count by service type by process unit.

Only two refineries met these criteria and, therefore, the equipment leak database is comprised of these two data sets. Table 3-1 presents the equipment counts by service type by process unit for both refineries. Tables 3-2 and 3-3 present the HAP emissions by source type by process unit reported by the refineries included in the database (Refineries C and I, respectively). Table 3-4 presents the HAP emissions reported by the remaining California refineries submitting data.

### 3.2.2 Development of Hazardous Air Pollutant Emission Factors

Hazardous air pollutant emission factors were developed to characterize the equipment leak database. The HAP emission factors were generated by dividing the specific HAP emissions reported by each refinery for a specific process by the equipment counts by service type reported for that particular process. The average HAP emissions factors were then calculated from the two data sets. Table 3-5 presents the average HAP emission factors (in lbs/yr/1,000 equipment counts) for each process unit.

### 3.2.3 Database Limitations and Variability

The equipment leak database has some significant gaps. Neither Refinery C or I reported equipment count or HAP emission information on aromatics/isomerization or coking processes; therefore, HAP emission factors could not be calculated for these processes. Information on catalytic hydrocracking, catalytic hydrotreating, lubes, and asphalt processes was only reported by Refinery C. Hazardous air pollutant emission factors for these processes were generated from this refinery only.

Refinery C did not report pumps for sulfur units or compressors for catalytic hydrocracking, alkylation, lubes, asphalt, or sulfur units. Refinery I did not report compressor component counts for crude, thermal, catalytic reforming, hydrogen, or sulfur units; PRV's for catalytic reforming and

sulfur units; or light liquid pumps for vacuum distillation, hydrogen, and sulfur units.

Seven HAP chemicals (benzene, toluene, xylene, cresol, 1,3-butadiene, ethyl-benzene, naphthalene) were reported by Refinery C. Refinery I only reported benzene, toluene, xylene, and 1,3-butadiene. The California refineries not included in the database reported 23 different HAP's among them. Refinery C did not report any HAP emissions from gas valves or compressors, and only reported naphthalene as being emitted from heavy liquid valves and pumps. Refinery C only reported 1,3-butadiene emissions from its hydrogen unit. Refinery I only reported 1,3-butadiene emissions for gas valves and compressors. Because of lack of data, large gaps occur when calculating the HAP emission factors.

### 3.3 REFERENCES

1. VOC Fugitive Emissions in Petroleum Refining Industry - Background Information for Proposed Standards. Office of Air Quality Planning and Standards. U.S. Environmental Protection Agency. EPA-450/3-81-015a. November 1982.

TABLE 3-1. EQUIPMENT COUNTS BY PROCESS

| Company | Equipment  | Service    | Crude | Vacuum dist. | Thermal operations | Cat cracking | Cat reforming | Cat cracking | Cat hydro refining | Cat hydro treating | Alkylation | Lubes | Asphalt | Hydrogen | Sulfur |
|---------|------------|------------|-------|--------------|--------------------|--------------|---------------|--------------|--------------------|--------------------|------------|-------|---------|----------|--------|
| C       | Valves     | Gas        | 134   | 136          | 406                | 455          | 286           | 205          | 300                | 609                | 860        | 164   | 75      | 1,187    | 324    |
|         | .          | Lt.liquid  | 750   | 83           | 772                | 455          | 357           | 273          | 180                | 816                | 1,178      | 304   | 75      | 792      | 324    |
|         |            | Hvy.liquid | 952   | 635          | 2,886              | 606          | 71            | 205          | 120                | 84                 | 113        | 1,170 | 603     |          | 72     |
|         | Pumps      | Lt.liquid  | 25    |              | 45                 | 28           | 20            | 26           | 11                 | 21                 | 46         | 33    | 11      | 28       |        |
|         |            | Hvy.liquid | 22    | 15           | 54                 | 38           | 5             | 30           | 9                  | 54                 | 19         | 118   | 39      | 11       |        |
|         | Compressor |            | 1     | 1            | 3                  | 4            | 4             |              | 1                  | 4                  |            |       |         | 4        |        |
|         | Flanges    |            | 5,380 | 5,380        | 16,257             | 6,062        | 2,859         | 2,735        | 2,400              | 6,038              | 8,603      | 6,552 | 3,017   | 7,915    | 2,882  |
| I       | PRV's      |            | 2     | 1            | 1                  | 2            | 3             | 3            | 2                  | 6                  | 3          | 15    | 5       | 4        | 1      |
|         | Valves     | Gas        | 218   | 540          | 592                | 1,390        | 748           |              |                    | 1,005              | 944        |       |         | 223      | 736    |
|         |            | Lt.liquid  | 636   | 47           | 329                | 921          | 206           |              |                    | 1,523              | 1,606      |       |         | 34       | 34     |
|         |            | Hvy.liquid | 1,571 | 1,277        | 955                | 1,323        | 10            |              |                    | 778                | 536        |       |         | 49       | 263    |
|         | Pumps      | Lt.liquid  | 21    |              | 16                 | 27           | 5             |              |                    | 13                 | 45         |       |         | 5        | 11     |
|         |            | Hvy.liquid | 34    | 28           | 27                 | 34           | 1             |              |                    | 21                 | 1          |       |         |          |        |
|         | Compressor |            |       | 1            |                    | 5            |               |              |                    | 4                  | 1          |       |         |          |        |
|         | Flanges    |            | 2,425 | 1,864        | 1,876              | 3,634        | 964           |              |                    | 3,306              | 3,066      |       |         | 306      | 1,033  |
|         | PRV's      |            | 9     | 2            | 3                  | 16           |               |              |                    | 6                  | 40         |       |         | 2        |        |

Note: A blank entry indicates no data were reported

TABLE 3-2. HAZARDOUS AIR POLLUTANT EMISSIONS BY PROCESS FOR REFINERY C\* (lb/yr)

| Equipment         | Pollutants    | Crude | Vacuum dist. | Thermal operations | Cat cracking | Cat reforming | Cat hydro cracking | Cat hydro refining | Cat hydro treating | Alkylation | Lubes | Asphalt | Hydrogen | Total  |
|-------------------|---------------|-------|--------------|--------------------|--------------|---------------|--------------------|--------------------|--------------------|------------|-------|---------|----------|--------|
| <b>Gas valves</b> |               |       |              |                    |              |               |                    |                    |                    |            |       |         |          |        |
| LL valves         | Benzene       | 140   |              | 20.7               | 21.6         | 66.4          | 11.3               | 0.14               | 78.9               | 0.83       | 0.098 | 0.041   |          | 340    |
|                   | Toluene       | 1.07  |              | 10.9               | 57.5         | 498           | 8.04               | 0.14               | 5.65               | 0.83       | 0.098 | 0.041   |          | 582    |
|                   | Xylene        | 1.07  |              | 10.9               | 57.5         | 498           | 8.04               | 0.14               | 5.65               | 0.83       | 0.098 | 0.041   |          | 582    |
|                   | 1,3-Butadiene |       |              | 10.9               | 28.7         | 3.32          | 1.61               |                    |                    | 44.0       |       |         | 0.763    | 89.3   |
|                   | Cresol        |       |              | 10.9               | 28.7         |               | 0.161              |                    |                    |            |       |         |          | 39.8   |
| <b>HL valves</b>  |               |       |              |                    |              |               |                    |                    |                    |            |       |         |          |        |
|                   | Naphthalene   | 174   | 174          | 631                | 13.3         | 1.57          | 4.5                | 26.3               | 14.7               |            | 256   | 132     |          | 1,427  |
| LL pumps          | Benzene       | 38.3  |              | 50.7               | 124          | 237           | 108                | 0.65               | 119                | 1.66       | 1.54  | 0.65    |          | 681    |
|                   | Toluene       | 3.00  |              | 26.6               | 331          | 1,774         | 77.0               | 0.65               | 24.9               | 1.66       | 1.54  | 0.65    |          | 2,241  |
|                   | Xylene        | 3.00  |              | 26.6               | 331          | 1,774         | 77.0               | 0.65               | 24.9               | 1.66       | 1.54  | 0.65    |          | 2,241  |
|                   | 1,3-Butadiene |       |              | 26.6               | 16.6         | 11.8          | 1.54               |                    | 0.355              | 54.9       |       |         | 1.65     | 114    |
|                   | Ethyl-benzene | 14.8  |              | 26.6               | 82.9         | 237           | 77.0               | 0.65               | 26.6               | 1.66       | 1.54  | 0.65    |          | 469    |
|                   | Cresol        |       |              | 26.6               | 16.6         |               | 15.4               |                    |                    |            |       |         |          | 58.6   |
| <b>HL pumps</b>   |               |       |              |                    |              |               |                    |                    |                    |            |       |         |          |        |
|                   | Naphthalene   | 101   | 101          | 294                | 20.7         | 2.72          | 16.3               | 48.9               | 267                |            | 642   | 212     |          | 1,706  |
| <b>Compressor</b> |               |       |              |                    |              |               |                    |                    |                    |            |       |         |          |        |
| Flange            | Benzene       | 42.5  |              | 28.8               | 66.9         | 140           | 37.6               | 0.353              | 145                | 1.11       | 120   | 0.148   |          | 582    |
|                   | Toluene       | 3.27  |              | 15.2               | 178          | 1052          | 26.8               | 0.353              | 33.5               | 1.11       | 11.3  | 0.148   |          | 1,322  |
|                   | Xylene        | 3.27  |              | 15.2               | 178          | 1052          | 26.8               | 0.353              | 33.5               | 1.11       | 11.3  | 0.148   |          | 1,322  |
|                   | 1,3-Butadiene |       |              | 15.2               | 8.93         | 7.0           | 0.537              |                    | 0.50               | 61.4       |       |         | 1.55     | 95.1   |
|                   | Ethyl-benzene | 16.4  |              | 15.2               | 44.6         | 140           | 26.8               | 0.353              | 36.1               | 1.11       | 11.3  | 0.148   |          | 292    |
|                   | Cresol        |       |              | 15.2               | 8.93         |               | 5.37               |                    |                    |            |       |         |          | 29.5   |
|                   | Naphthalene   | 779   | 779          | 2,831              | 59.5         | 7.0           | 20.2               | 118                | 65.7               |            | 883   | 592     |          | 6,133  |
| PRV               | Benzene       | 5.18  |              | 1.60               | 6.75         | 39.8          | 14.0               | 0.09               | 33.3               | 0.084      | 0.569 | 0.285   |          | 102    |
|                   | Toluene       | 0.400 |              | 0.84               | 18.0         | 300           | 10.0               | 0.09               | 7.33               | 0.084      | 0.569 | 0.285   |          | 338    |
|                   | Xylene        | 0.400 |              | 0.84               | 18.0         | 300           | 10.0               | 0.09               | 7.33               | 0.084      | 0.569 | 0.285   |          | 338    |
|                   | 1,3-Butadiene |       |              | 0.84               | 0.898        | 2.0           | 0.2                |                    | 0.090              | 4.57       |       |         | 0.284    | 8.9    |
|                   | Ethyl-benzene | 2.00  |              | 0.84               | 4.49         | 39.8          | 10.0               | 0.09               | 7.33               | 0.084      | 0.569 | 0.285   |          | 65.4   |
|                   | Cresol        |       |              | 0.84               | 0.898        |               | 2.00               |                    |                    |            |       |         |          | 3.73   |
|                   | TOTAL         | 1,328 | 1,054        | 4,115              | 1,724        | 8,183         | 591                | 198                | 937                | 179        | 1,943 | 941     | 4.25     | 21,184 |

\* Refinery C did not report HAP emissions from sulfur, aromatics/isomerization, or coke units.

Note: A blank entry indicates no data were reported

TABLE 3-3. HAZARDOUS AIR POLLUTANT EMISSIONS BY PROCESS FOR REFINERY I\*  
(lb/yr)

| Equipment  | Pollutant     | Crude  | Vacuum dist. | Thermal operations | Cat cracking | Cat reforming | Cat hydro treating | Alkylation | Hydrogen | Sulfur | Total  |
|------------|---------------|--------|--------------|--------------------|--------------|---------------|--------------------|------------|----------|--------|--------|
| Gas valves | 1,3-Butadiene | 0.0206 | 0.0206       | 0.0206             | 0.0255       | 0.0678        | 0.0192             | 0.342      | 0.0666   | 0.0354 | 0.619  |
| LL valves  | Benzene       | 829    | 7.79         | 248                | 546          | 147           | 570                | 274        |          | 0.202  | 2,622  |
|            | Toluene       | 647    | 64.0         | 149                | 1,997        | 990           | 3,313              | 727        |          | 93.6   | 7,981  |
|            | Xylene        | 702    | 77.9         | 181                | 1,859        | 824           | 6,881              | 37.1       |          |        | 10,562 |
|            | 1,3-Butadiene | 12.9   |              | 15.2               | 93.8         |               |                    | 197        | 0.222    |        | 319    |
| HL valves  | Benzene       | 4.50   |              | 1.10               | 1.76         | 0.017         | 4.58               | 0.236      | 0.0066   | 0.0044 | 12.2   |
|            | Toluene       | 11.9   | 0.687        | 3.90               | 5.80         | 1.90          | 4.75               | 1.65       | 4.05     | 2.02   | 36.7   |
|            | Xylene        | 16.7   | 1.63         | 8.60               | 10.21        | 2.26          | 15.5               | 4.00       | 4.40     | 2.20   | 65.5   |
|            | 1,3-Butadiene |        |              |                    |              |               |                    | 0.017      |          |        | 0.017  |
| LL pumps   | Benzene       | 224    |              | 7.30               | 198          |               | 59.2               | 0.0016     |          |        | 488    |
|            | Toluene       | 158    |              | 62.1               | 589          |               | 566                | 0.624      |          |        | 1,377  |
|            | Xylene        | 172    |              | 80.5               | 236          |               | 1,064              | 1.74       |          |        | 1,554  |
|            | 1,3-Butadiene | 3.50   |              | 6.50               | 0.46         |               |                    | 101        |          |        | 112    |
| HL pumps   | Benzene       | 6.70   | 0.0085       | 4.10               | 0.761        | 0.196         | 0.225              | 0.121      |          |        | 12.1   |
|            | Toluene       | 18.2   | 0.660        | 0.700              | 6.81         | 0.450         | 15.7               | 0.683      |          |        | 43.2   |
|            | Xylene        | 26.2   | 1.56         | 15.3               | 14.1         | 0.523         | 46.3               | 1.61       |          |        | 106    |
| Compressor | 1,3-Butadiene |        |              |                    |              |               | 0.0257             | 0.0283     |          |        | 0.0540 |
| Flanges    | Benzene       | 73.2   | 0.650        | 21.6               | 46.1         | 12.2          | 53.6               | 23.1       | 0.0096   | 0.0216 | 230    |
|            | Toluene       | 66.5   | 6.06         | 16.6               | 168          | 82.3          | 285                | 62.4       | 4.51     | 9.92   | 701    |
|            | Xylene        | 76.6   | 8.26         | 24.5               | 160          | 68.8          | 596                | 7.54       | 4.90     | 10.8   | 957    |
|            | 1,3-Butadiene | 1.10   | 0.009        | 1.30               | 7.59         | 0.018         | 0.010              | 16.6       | 0.024    | 0.012  | 26.7   |
| PRV        | Benzene       | 212    |              |                    | 119          |               | 171                | 0.0011     |          |        | 502    |
|            | Toluene       | 130    |              |                    | 373          |               | 49.1               | 0.454      |          |        | 553    |
|            | Xylene        | 142    |              |                    | 202          |               | 58.2               | 1.28       |          |        | 403    |
|            | 1,3-Butadiene | 3.80   |              | 2.00               | 9.59         |               |                    | 263        | 0.0257   |        | 278    |
|            | TOTAL         | 3,538  | 169          | 849                | 6,644        | 2,130         | 13,752             | 1,722      | 18       | 119    | 28,943 |

\* Refinery I did not report HAP emissions from catalytic hydrocracking, catalytic hydrotreating, lubes, asphalt, coke, or aromatics/isomerization units.

Note: A blank entry indicates no data were reported

TABLE 3-4. HAZARDOUS AIR POLLUTANT EMISSIONS FROM REFINERIES (lb/yr)

| Pollutants            | Refineries |        |       |      |        |        |       |        |        |        |        |
|-----------------------|------------|--------|-------|------|--------|--------|-------|--------|--------|--------|--------|
|                       | A          | B      | C     | D    | E      | F      | G     | H      | I      | J      | K      |
| Acetaldehyde          |            |        |       |      |        |        | 1.78  |        |        |        |        |
| Benzene               | 7,140      | 4,120  | 1,705 | 38.1 | 5,173  | 5,132  | 2,151 | 3,067  | 3,866  | 4,820  | 3,163  |
| 1,3-Butadiene         | 670        | 83.8   | 307   |      | 161    |        |       | 269    | 736    | 1,331  |        |
| Carbon tetrachloride  |            |        |       |      |        | 30     |       |        |        |        |        |
| Chlorine              |            | 44.6   |       |      | 135    |        |       | 0.0281 |        |        |        |
| Chlorobenzene         |            |        |       | 33.1 |        |        |       |        |        |        |        |
| Chloroform            |            |        |       | 33.1 |        | 60     |       |        |        |        |        |
| Cresol                | 409        |        | 132   | 38.4 |        |        |       |        |        |        | 55.9   |
| 1,4-Dioxane           |            |        |       | 665  |        |        |       |        |        |        |        |
| Ethyl benzene         |            |        | 826   |      |        |        |       |        |        |        |        |
| Ethylene dibromide    |            | 6.25   |       | 33.1 |        |        |       | 1.63   |        |        |        |
| Ethylene dichloride   |            | 0.115  |       | 33.1 |        |        |       |        |        |        |        |
| Ethylene glycol       |            |        |       |      |        | 1,800  |       |        |        |        |        |
| Hydrochloric acid     |            |        |       | 513  |        |        |       |        |        |        |        |
| Hydrogen fluoride     |            |        |       |      |        |        |       |        |        |        |        |
| Methyl chloroform     |            |        |       |      |        | 2,953  |       | 304    |        |        |        |
| Naphthalene           |            | 418    | 9,266 | 42.6 | 334    | 400    | 417   | 0.0316 |        | 358    | 2,030  |
| Phenol                |            |        |       | 33.5 |        | 17,794 |       | 2,660  |        | 76     | 30.6   |
| Toluene               | 35,603     | 17,813 | 4,483 | 133  | 21,119 | 16,200 | 6,613 | 74.4   | 10,692 | 10,892 | 6,841  |
| 1,1,1-Trichloroethane |            | 477    |       |      |        |        |       |        |        |        |        |
| Xylenes               | 49,213     | 12,226 | 4,483 | 236  | 9,248  | 21,616 | 6,288 | 7,169  | 13,648 | 12,022 | 13,916 |

Note: A blank entry indicates no data were reported

TABLE 3-5. HAZARDOUS AIR POLLUTANT EMISSION FACTORS (lb/yr/1,000 Equipment Counts)

| Equipment   | Pollutant     | Crude  | Vacuum dist. | Thermal operations | Cat cracking | Cat reforming | Cat hydro cracking | Cat hydro refining | Alkylation | Lubes  | Asphalt | Hydrogen | Sulfur |
|-------------|---------------|--------|--------------|--------------------|--------------|---------------|--------------------|--------------------|------------|--------|---------|----------|--------|
| Gas valves  | 1,3-Butadiene | 0.0945 | 0.0381       | 0.0348             | 0.0183       | 0.0906        |                    |                    | 0.0191     | 0.362  |         | 0.299    | 0.0481 |
| LL valves   | Benzene       | 745    | 16.6         | 390                | 320          | 450           | 414                | 0.778              | 235        | 85.7   | 0.322   | 0.546    | 5.95   |
|             | Cresol        |        |              | 14.1               | 63.1         |               | 0.589              |                    |            |        |         |          |        |
|             | Toluene       | 509    | 1,362        | 233                | 1,147        | 3,100         | 29.5               | 0.778              | 1,091      | 227    | 0.322   | 0.546    | 2,753  |
|             | Xylene        | 552    | 1,657        | 282                | 1,071        | 2,697         | 29.5               | 0.778              | 2,262      | 11.9   | 0.322   | 0.546    |        |
|             | 1,3-Butadiene | 20.2   |              | 30.2               | 82.5         | 9.30          | 5.90               |                    |            | 80.0   |         | 3.75     |        |
| HL valves   | Benzene       | 2.86   | 0.0038       | 1.15               | 1.33         | 1.65          |                    |                    | 5.89       | 0.440  |         | 0.135    | 0.0167 |
|             | Naphthalene   | 183    | 274          | 219                | 21.9         | 22.1          | 21.9               | 219                | 175        |        | 218     | 219      |        |
|             | Toluene       | 7.57   | 0.538        | 4.08               | 4.38         | 190           |                    |                    | 6.11       | 3.07   |         | 82.6     | 7.70   |
|             | Xylene        | 10.6   | 1.28         | 9.01               | 7.72         | 226           |                    |                    | 19.9       | 7.46   |         | 89.8     | 8.37   |
|             | 1,3-Butadiene |        |              |                    |              |               |                    |                    |            | 0.0322 |         |          |        |
| LL pumps    | Benzene       | 6,099  |              | 791                | 5,881        | 11,850        | 4,154              | 59.1               | 5,110      | 18.1   | 46.7    | 59.1     |        |
|             | Cresol        |        |              | 591                | 592          |               | 592                |                    |            |        |         |          |        |
|             | Ethyl-benzene | 592    |              | 591                | 2,961        | 11,850        | 2,962              | 59.1               | 1,267      | 36.1   | 46.7    | 59.1     |        |
|             | Toluene       | 3,822  |              | 2,236              | 16,818       | 88,700        | 2,962              | 59.1               | 22,362     | 24.9   | 46.7    | 59.1     |        |
|             | Xylene        | 4,155  |              | 2,811              | 10,281       | 88,700        | 2,962              | 59.1               | 41,516     | 37.4   | 46.7    | 59.1     |        |
|             | 1,3-Butadiene | 167    |              | 499                | 305          | 590           | 59.2               |                    | 16.9       | 1,719  |         | 58.9     |        |
| HL pumps    | Benzene       | 197    | 0.305        | 152                | 22.4         | 196           |                    |                    | 10.7       | 121    |         |          |        |
|             | Naphthalene   | 4,591  | 6,733        | 5,444              | 545          | 544           | 544                | 5,433              | 4,944      |        | 5,441   | 5,436    |        |
|             | Toluene       | 535    | 23.6         | 25.9               | 200          | 450           |                    |                    | 749        | 683    |         |          |        |
|             | Xylene        | 771    | 55.9         | 567                | 416          | 523           |                    |                    | 2,207      | 1,608  |         |          |        |
| Compressors | 1,3-Butadiene |        |              |                    |              |               |                    |                    | 6.43       | 28.3   |         |          |        |
| Flanges     | Benzene       | 19.0   | 0.149        | 6.64               | 11.9         | 30.8          | 13.7               | 0.147              | 20.1       | 3.76   | 18.3    | 0.049    | 0.021  |
|             | Cresol        |        |              | 0.934              | 1.47         |               | 1.96               |                    |            |        |         |          |        |
|             | Ethyl-benzene | 3.05   |              | 0.934              | 7.36         | 48.9          | 7.39               | 0.147              | 5.98       | 3.83   | 1.72    | 0.049    |        |
|             | Naphthalene   | 145    | 145          | 174                | 9.82         | 2.45          | 9.79               | 49.2               | 10.9       | 0.129  | 135     | 196      |        |
|             | Toluene       | 14.0   | 3.25         | 4.89               | 37.8         | 227           | 9.79               | 0.147              | 45.9       | 10.2   | 1.72    | 0.049    | 14.7   |
|             | Xylene        | 16.1   | 2.22         | 6.99               | 36.7         | 219           | 9.79               | 0.147              | 92.9       | 1.29   | 1.72    | 0.049    | 9.60   |
|             | 1,3-Butadiene | 0.227  | 0.0044       | 0.813              | 1.78         | 1.23          | 0.196              |                    | 0.0420     | 6.28   |         | 16.1     | 10.4   |
|             |               |        |              |                    |              |               |                    |                    |            |        |         | 0.137    | 0.0113 |
| PRV'S       | Benzene       | 13,073 |              | 1,600              | 5,406        | 13,262        | 4,667              | 45                 | 17,025     | 14.0   | 38.0    | 57       |        |
|             | Cresol        |        |              | 840                | 449          |               | 667                |                    |            |        |         |          |        |
|             | Ethyl-benzene | 1,000  |              | 840                | 2,245        | 13,262        | 3,333              | 45                 | 1,222      | 28.0   | 38.0    | 57       |        |
|             | Toluene       | 7,322  |              | 840                | 16,159       | 100,000       | 3,333              | 45                 | 4,703      | 19.7   | 38.0    | 57       |        |
|             | Xylene        | 7,989  |              | 840                | 10,803       | 100,000       | 3,333              | 45                 | 5,461      | 30.0   | 38.0    | 57       |        |
|             | 1,3-Butadiene | 422    |              | 753                | 524          | 666           | 66.7               |                    | 15.7       | 4,049  |         | 42       |        |

Note: A blank entry indicates no emissions or equipment counts were reported

## 4.0 STORAGE TANKS

### 4.1 BACKGROUND INFORMATION

#### 4.1.1 Types of Storage Tanks

Most storage tanks at petroleum refineries are comprised of three basic tank designs: fixed roof, external floating roof, and internal floating roof. Some general information about the design of these tanks and their emissions is provided below. Additional information about storage tanks can be found in AP-42.<sup>1</sup>

4.1.1.1 Fixed Roof Tanks. This type of tank is generally considered the minimum acceptable equipment design for storage of petroleum liquids. It consists of a cylindrical steel shell with a permanently affixed roof and is commonly equipped with a pressure/vacuum valve.

Two types of emissions from fixed roof tanks are breathing losses and working losses. Breathing loss is the expulsion of vapor from a tank through vapor expansion and contraction due to changes in temperature and barometric pressure. This loss occurs without any liquid level change in the tank.

Working loss is the combined loss from filling and emptying the tank. Filling loss occurs during an increase of the liquid level in the tank, when the pressure inside the tank exceeds the relief pressure and vapors are expelled. Emptying loss occurs when air drawn into the tank during liquid removal becomes saturated with organic vapor and expands, thus exceeding the vapor space capacity.

Fixed roof emissions vary as a function of tank size, vapor pressure of the stored petroleum liquid, turnovers per year, and meteorological conditions at the tank location.

4.1.1.2 External Floating Roof Tanks. External floating roof tanks consist of a cylindrical steel shell with a roof floating on the surface of the stored petroleum liquid. There is

an annular rim seal attached to the perimeter of the tank, with roof fittings for operational functions. Current external floating roof designs are pan-type, pontoon-type, and double deck-type roofs.

Floating roofs may have a primary (lower) and a secondary (upper) seal. The primary seal may be either a metallic shoe seal, a liquid-mounted seal, or a vapor-mounted seal. Secondary seals may be rim-mounted or shoe-mounted.

Emissions from external floating roof tanks are the sum of standing storage losses and withdrawal losses. Standing storage losses include rim seal losses and deck fitting losses. Withdrawal loss occurs as the liquid that clings to the tank wall is exposed to the atmosphere and vaporizes when the floating roof is lowered by withdrawal of the stored liquid.

4.1.1.3 Internal Floating Roof Tanks. An internal floating roof tank has both a permanent fixed roof and a floating deck inside. There are two basic types of internal floating roof tanks: 1) tanks in which the fixed roof is supported by vertical columns within the tank, and 2) tanks with a self-supported fixed roof and no internal support columns.

Internal floating roof tanks are equipped with a continuous closure device, such as a foam-or liquid-filled seal, two seals (primary and secondary) mounted one above the other, or a mechanical shoe seal, between the wall and the internal roof.

Total emissions from internal floating roof tanks are the sum of standing losses and withdrawal losses. Standing storage losses include rim seal losses, deck fitting losses, and deck seam losses.

#### 4.1.2 Types of Petroleum Liquid Stored in Tanks

Petroleum liquids stored at petroleum refineries may be divided into three categories: 1) crude oil, 2) high vapor pressure petroleum liquids, and 3) low vapor pressure petroleum liquids. Because most state regulations base their requirements on vapor pressure and tank size, there are common storage practices for specific petroleum liquids.

Crude oil has a wide range of vapor pressures and is usually stored in large external floating roof tanks. High vapor pressure petroleum liquids, such as naphtha, jet naphtha (JP-4), benzene, and gasoline, are commonly stored in large internal floating roof tanks. Low vapor pressure petroleum liquids, such as distillate fuel oil, heavy gas oil, and residual fuel oil, are generally stored in fixed roof tanks.<sup>2</sup>

#### 4.2 METHOD FOR DEVELOPING HAZARDOUS AIR POLLUTANT EMISSION FACTORS FOR STORAGE TANKS

The methodology used for developing speciated hazardous air pollutant (HAP) emission factors for refinery storage tanks involved compiling information from the California refinery database and developing correlations between HAP emissions and specific refinery process unit charge capacity, as discussed below.

##### 4.2.1 California Refinery Storage Tank Database

The minimum information required for a specific storage tank to be included in the California refinery database was:

- type of tank;
- type of petroleum liquid stored; and
- annual average emissions by HAP (lbs/yr) (total loss).

Additional information about storage capacity; throughput; seal design; breathing, standing, working, and withdrawal losses; and refinery process was compiled when available. The California refinery database is comprised of 487 storage tanks. The tank types in this database include fixed roof, external floating roof, and internal floating roof tanks.

Table 4-1 presents the petroleum liquids included in the California refinery database and the refinery process unit to which each liquid was assigned.

The annual average emissions by HAP were obtained from Forms "PRO-Process and Emittents Data" used by California refineries to comply with Air Toxics "Hot Spots" Information and Assessment Act of 1987 (AB 2588). These emissions were calculated using AP-42 equations for total VOC emissions, and then coupled with

composition data obtained for refinery streams. Fourteen HAP's were reported as being released from storage tanks. Only benzene, toluene, and xylene were reported by all refineries comprising the California database. Table 4-2 shows the various HAP's reported by each refinery included in the database.

Tables 4-3 through 4-10 present the HAP emissions from storage tanks reported by each of the 8 California refineries included in the database.

Table 4-11 presents a summary of the reported number of tanks by petroleum liquid type from California refineries in the database. External floating roof storage tanks was the tank type most represented in the database.

#### 4.2.2 Development of Hazardous Air Pollutant Emission Factors

Tank emission factors by petroleum liquid and tank type were developed on the basis of the respective refinery process charge capacity.

The assignment of storage tanks to a specific refinery process was made according to the scheme listed in Table 4-1. With some petroleum liquids, it was possible to assign tanks to a specific process. For example, reformate can be assigned to the catalytic reforming unit and xylene can be assigned to the aromatics unit. However, with blended hydrocarbon products (gasolines, diesel fuels, jet fuels, and fuel oils) it was difficult to assign the tanks to a specific unit because more than one unit is involved. For example, gasoline is typically a blend of various petroleum liquid fractions: reformate, alkylate, straight-run gasoline, thermally cracked gasoline, catalytically cracked gasoline, coker gasoline, isomate, and butane. Therefore, the crude unit was selected as a default when a specific refinery process unit could not be assigned.

Tank emission factors for each HAP were obtained by dividing the reported HAP emissions from each refinery (for a specific petroleum liquid and tank type) by the total refinery process charge capacity of those refineries reporting the specific HAP. Information on types and capacities of refinery processes included in the database were identified using the Oil and Gas

### Journal's January 1990 Annual Refining Survey.3

Table 4-12 presents tank emission factors for 14 HAP's by petroleum liquid and tank type expressed as lb/yr per 1,000 bbl/sday refinery process capacity.

4.2.2.1 Analysis of Tank Emission Factors. Tank emission factors by HAP range from  $4.43 \times 10^{-8}$  to 26.3 lb/yr per 1,000 bbl/sday. The lowest emission factor is for phenol (fixed roof tanks storing others) and the highest emission factor is for toluene (fixed roof tanks storing toluene).

For tanks storing gasoline, toluene was the HAP with the highest emission factor.

#### 4.3 REFERENCES

1. U.S. Environmental Protection Agency. Compilation of Air Pollutant Emission Factors. Volume 1: Stationary Point and Area Sources. Office of Air Quality Planning and Standards. Research Triangle Park, North Carolina. AP-42. Fourth Edition. September 1985.
2. U.S. Environmental Protection Agency. Estimating Air Toxics Emissions from Organic Liquid Storage Tanks. Office of Air Quality Planning and Standards. Research Triangle Park, North Carolina. EPA-450/4-88-004. October 1988.
3. Thrash, L.A. Annual Refining Survey. Oil & Gas Journal. March 26, 1990.

TABLE 4-1. LIST OF PETROLEUM LIQUID TYPES AND  
REFINERY PROCESS ASSIGNMENT

| Petroleum liquid type  | Refinery process    |
|------------------------|---------------------|
| Alkylate               | Alkylation          |
| Crude                  | Crude               |
| Diesel/distillate fuel | Crude               |
| Gasoline               | Crude               |
| Jet/kerosene           | Crude               |
| Kerosene               | Crude               |
| Naphtha                | Crude               |
| Others                 | Crude               |
| Reformate              | Catalytic reforming |
| Residual fuel oil      | Crude               |
| Slop oil               | Crude               |
| Toluene                | Aromatics           |
| Xylene                 | Aromatics           |

TABLE 4-2. HAZARDOUS AIR POLLUTANTS REPORTED BY  
EACH REFINERY INCLUDED IN DATABASE

| HAP                  | Refinery                     |
|----------------------|------------------------------|
| Benzene              | A, B, D, E, F, G, H, I, J, K |
| Carbon tetrachloride | A                            |
| Chlorobenzene        | D                            |
| Chloroform           | D                            |
| Cresol               | D, K                         |
| 1,4 Dioxane          | D                            |
| Ethylene dichloride  | A, D, E, F, G, J             |
| Ethylene dibromide   | D, E, G, H, J                |
| Glycol ethers        | G                            |
| Naphthalene          | B, D, E, G, H, J, K          |
| Phenol               | D, F, K                      |
| Styrene              | D                            |
| Toluene              | A, B, D, E, F, G, I, J, K    |
| Xylene               | A, B, D, E, F, G, I, J, K    |

Note: Refinery C did not report any HAP emissions from storage tanks.

TABLE 4-3. STORAGE TANK EMISSIONS - REFINERY A

| Tank type*             | Petroleum liquid type | Throughput (Mbbl/yr)** | HAP Emissions (lb/yr) |                      |                     |                |
|------------------------|-----------------------|------------------------|-----------------------|----------------------|---------------------|----------------|
|                        |                       |                        | Benzene               | Carbon tetrachloride | Ethylene dichloride | Toluene Xylene |
| FIX                    | Crude                 |                        | 6.5                   |                      |                     | 16.4 7.8       |
| FIX                    | Crude                 |                        | 8.3                   |                      |                     | 20.8 9.93      |
| FIX                    | Crude                 |                        | 19.2                  |                      |                     | 48.4 23        |
| FIX                    | Crude                 |                        | 19.1                  |                      |                     | 48.2 23        |
| FIX                    | Crude                 |                        | 19.2                  |                      |                     | 48.5 23.1      |
| FIX                    | Crude                 |                        | 13.6                  |                      |                     | 34.2 16.4      |
| FIX                    | Other                 |                        |                       | 0.11                 |                     |                |
| FR                     | Gasoline              |                        | 33.6                  |                      |                     | 128 31.5       |
| FR                     | Gasoline              |                        | 2.36                  |                      | 0.1                 | 1.8 0.3        |
| FR                     | Gasoline              |                        | 123                   |                      |                     |                |
| FR                     | Gasoline              |                        | 33                    |                      |                     | 126 31         |
| FR                     | Gasoline              |                        | 6                     |                      |                     | 64 155         |
| FR                     | Gasoline              |                        | 178                   |                      |                     | 624 802        |
| FR                     | Gasoline              |                        | 371                   |                      |                     | 349 108        |
| FR                     | Gasoline              |                        | 35.7                  |                      | 0.4                 | 136 33.5       |
| FR                     | Gasoline              |                        | 33                    |                      |                     | 126 31         |
| FR                     | Gasoline              |                        | 34                    |                      | 0.3                 | 129 32         |
| FR                     | Gasoline              |                        | 33.9                  |                      |                     | 129 31.9       |
| FR                     | Gasoline              |                        | 35.8                  |                      |                     | 136 33.6       |
| FR                     | Gasoline              |                        | 63                    |                      |                     | 627 1,510      |
| FR                     | Gasoline              |                        | 10                    |                      | 0.3                 | 38 9           |
| IFR                    | Gasoline              |                        | 14.8                  |                      | 0.2                 | 56.5 13.9      |
| IFR                    | Gasoline              |                        | 11.6                  |                      | 0.1                 | 44.3 10.9      |
| IFR                    | Gasoline              |                        | 11.6                  |                      |                     | 44 10.9        |
| IFR                    | Gasoline              |                        | 14.8                  |                      |                     | 57 13.9        |
| IFR                    | Gasoline              |                        | 11.5                  |                      |                     | 44 10.8        |
| Total emissions by HAP |                       |                        | 1,140                 | 0.11                 | 1.4                 | 3,080 2,970    |

\*FIX = Fixed roof

FR = External floating roof

IFR = Internal floating roof

\*\* Confidential for this refinery.

**TABLE 4-4. STORAGE TANK EMISSIONS - REFINERY D**

| Petroleum              |                 | HAP Emissions (lb/yr) |                      |     |        |             |                     |                    |             |        |         |         |        |
|------------------------|-----------------|-----------------------|----------------------|-----|--------|-------------|---------------------|--------------------|-------------|--------|---------|---------|--------|
| Tank type*             | liquid type     | Throughput (Mbbbl/yr) | Chloro- benzene form |     | Cresol | 1,4 Dioxane | Ethylene dichloride | Ethylene dibromide | Naphthalene | Phenol | Styrene | Toluene | Xylene |
| IFR                    | Crude           | 11                    | 0.7                  | 0.1 | 1.3    |             |                     | 0.5                | 0.1         |        |         | 0.7     | 0.3    |
| IFR                    | Naphtha         | 99                    | 1.9                  | 0.2 | 3.6    |             | 13.7                | 0.3                | 1.5         |        | 0.1     | 1.8     | 0.9    |
| FIX                    | Kerosene        | 8.07                  | 2.2                  | 0.2 | 4.7    |             | 17.2                | 0.3                | 2           |        | 0.1     | 1.6     | 1.5    |
| FIX                    | Distillate fuel | 13.5                  | 18.8                 | 4.9 | 31.7   | 3.6         | 159                 | 4.5                | 10          | 7.2    | 3.5     | 22      | 37.1   |
| Total emissions by HAP |                 |                       | 23.6                 | 5.4 | 41.3   | 3.6         | 190                 | 5.6                | 13.6        | 3.1    | 7.2     | 26.1    | 39.8   |

\* FIX = Fixed roof

FR - External floating roof

IFR = Internal floating roof

TABLE 4-5. STORAGE TANK EMISSIONS - REFINERY E

| Tank<br>type* | Petroleum<br>liquid<br>type | Throughput<br>(Mbbl/yr) | HAP Emissions (lb/yr) |                        |                       |            |          |
|---------------|-----------------------------|-------------------------|-----------------------|------------------------|-----------------------|------------|----------|
|               |                             |                         | Benzene               | Ethylene<br>dichloride | Ethylene<br>dibromide | Napthalene | Toluene  |
| FR            | Alkylate                    | 1,580                   | 4.2                   |                        |                       |            | 12.1     |
| FR            | Crude                       | 8,300                   | 8.88                  |                        |                       |            | 13.1     |
| FR            | Crude                       | 2,560                   | 2.47                  |                        |                       |            | 0.812    |
| FR            | Crude                       | 36,200                  | 11.9                  |                        |                       |            | 11       |
| FR            | Crude                       | 9,010                   | 0.269                 |                        |                       |            | 0.53     |
| FR            | Crude                       | 22,700                  | 6.49                  |                        |                       |            | 6        |
| FR            | Crude                       | 39,300                  | 8.28                  |                        |                       |            | 7.65     |
| FR            | Crude                       | 10,600                  | 2.28                  |                        |                       |            | 0.748    |
| FR            | Crude                       | 5,190                   | 5.97                  |                        |                       |            | 8.84     |
| FR            | Gasoline                    | 11,000                  | 27                    | 0.0901                 | 0.0149                |            | 80.1     |
| FR            | Gasoline                    | 107                     | 6.04                  |                        |                       |            | 5.19     |
| FR            | Gasoline                    | 5,870                   | 27.4                  |                        |                       |            | 81.3     |
| FR            | Gasoline                    | 6,090                   | 21.3                  | 0.0914                 | 0.0151                |            | 3.5      |
| FR            | Gasoline                    |                         | 11.1                  |                        |                       |            | 32.8     |
| FR            | Gasoline                    | 902                     | 8.51                  |                        |                       |            | 7.32     |
| FR            | Gasoline                    | 3,000                   | 2.16                  |                        |                       | 0.113      | 5.05     |
| FR            | Gasoline                    | 12,200                  | 22                    |                        |                       |            | 25.2     |
| FR            | Gasoline                    | 1,510                   | 4.46                  |                        |                       |            | 13.2     |
| FR            | Gasoline                    | 2,750                   | 11.9                  |                        |                       |            | 13.7     |
| FR            | Gasoline                    | 8,000                   | 14.1                  |                        |                       |            | 24.4     |
| FR            | Gasoline                    | 6,910                   | 13.7                  |                        |                       |            | 23.6     |
| FR            | Gasoline                    | 3,140                   | 20.3                  |                        |                       |            | 35.2     |
| FR            | Gasoline                    | 112                     | 41.5                  |                        |                       |            | 47.7     |
| FR            | Gasoline                    | 6,940                   | 22.8                  |                        |                       |            | 39.3     |
| FR            | Gasoline                    | 6,310                   | 15.4                  |                        |                       |            | 17.6     |
| FR            | Gasoline                    | 138                     | 15.5                  |                        |                       |            | 17.7     |
| FR            | Jet kerosene                | 1                       | 3.86                  |                        | 0.0035                |            | 11.2     |
| FR            | Jet kerosene                | 1,010                   | 5.59                  | 0.0207                 | 0.0035                |            | 11.2     |
| FR            | Jet naphtha                 | 1,430                   | 67.6                  | 0.0299                 | 0.0051                |            | 16.2     |
| FR            | Jet naphtha                 | 4,800                   | 18                    |                        |                       |            | 30       |
| FR            | Jet naphtha                 | 2,490                   | 84.9                  |                        |                       |            | 8        |
| FR            | Other                       | 2,590                   | 9.03                  |                        |                       |            | 37.7     |
| FR            | Other                       | 1,810                   | 6.53                  |                        |                       |            | 5.02     |
| FR            | Other                       | 2,630                   | 10.1                  |                        |                       |            | 0.145    |
| FR            | Other                       | 2,860                   | 0.892                 |                        |                       | 0.00011    | 0.224    |
| FR            | Other                       | 1,840                   | 9.87                  |                        |                       |            | 2.08     |
| FR            | Other                       | 99                      | 3                     |                        |                       |            | 0.219    |
| FR            | Reformate                   | 776                     | 8.5                   |                        |                       |            | 0.0667   |
| FR            | Reformate                   | 2,020                   | 31                    |                        |                       |            | 0.0547   |
| FR            | Reformate                   | 4,310                   | 9.87                  |                        |                       |            | 10.4     |
| FR            | Reformate                   |                         |                       |                        |                       |            | 0.000198 |
| FR            | Reformate                   |                         |                       |                        |                       |            | 0.000726 |
| FR            | Reformate                   |                         |                       |                        |                       |            | 38.1     |
| FR            | Reformate                   |                         |                       |                        |                       |            | 0.000397 |
| FR            | Reformate                   |                         |                       |                        |                       |            | 0.219    |

(continued)

TABLE 4-5. (Continued)

| Tank type*             | Petroleum liquid type | Throughput (Mbbbl/yr) | HAP Emissions (lb/yr) |                     |                    |            |                |
|------------------------|-----------------------|-----------------------|-----------------------|---------------------|--------------------|------------|----------------|
|                        |                       |                       | Benzene               | Ethylene dichloride | Ethylene dibromide | Napthalene | Toluene Xylene |
| FR                     | Slop oil              | 1,210                 | 2.18                  |                     |                    | 2.02       | 0.11           |
| FR                     | Slop oil              | 190                   | 1.05                  |                     |                    | 0.967      | 0.235          |
| FR                     | Slop oil              | 785                   | 2.38                  |                     |                    | 2.2        | 0.535          |
| FR                     | Toluene               | 47.6                  |                       |                     |                    | 387        |                |
| IFR                    | Gasoline              | 121                   | 37.3                  |                     |                    | 110        | 274            |
| IFR                    | Jet kerosene          | 123                   | 59.3                  | 0.318               | 0.054              | 171        | 17.1           |
| IFR                    | Jet kerosene          | 212                   | 21.8                  | 0.116               | 0.0198             | 62.8       | 6.27           |
| IFR                    | Slop oil              | 71                    | 4.62                  |                     |                    | 4.27       | 0.219          |
| Total emissions by HAP |                       |                       | 733                   | 0.666               | 0.112              | 0.114      | 1,430          |
|                        |                       |                       |                       |                     |                    |            | 1,150          |

\*FIX - Fixed roof FR - External floating roof IFR - Internal floating roof

TABLE 4-6. STORAGE TANK EMISSIONS - REFINERY F

| Tank type* | Petroleum liquid type | Throughput (Mbbl/yr) | HAP Emissions (lb/yr) |                     |        |         |        |
|------------|-----------------------|----------------------|-----------------------|---------------------|--------|---------|--------|
|            |                       |                      | Benzene               | Ethylene dichloride | Phenol | Toluene | Xylene |
| FIX        | Crude oil             | 1,140                | 4.3                   |                     |        | 5.4     | 2.7    |
| FIX        | Crude oil             | 47.6                 | 2.1                   |                     |        | 2.7     | 1.4    |
| FIX        | Crude oil             | 4,520                | 4.6                   |                     |        |         |        |
| FIX        | Crude oil             | 5,170                | 20                    |                     |        |         | 13     |
| FIX        | Crude oil             | 4,520                | 4.4                   |                     |        |         |        |
| FIX        | Crude oil             | 9,120                | 2.3                   |                     |        |         |        |
| FIX        | Crude oil             | 5,170                | 18                    |                     |        |         | 12     |
| FIX        | Crude oil             | 5,170                | 20                    |                     |        |         | 14     |
| FIX        | Crude oil             | 310                  | 3.3                   |                     |        |         |        |
| FR         | Gasoline              | 1,020                | 11                    |                     |        | 17      | 7      |
| FR         | Gasoline              | 1,020                | 4                     |                     |        |         |        |
| FR         | Gasoline              | 1,020                | 9.8                   |                     |        |         |        |
| FR         | Gasoline              | 1,020                | 9.8                   |                     |        |         |        |
| FR         | Gasoline              | 833                  | 12                    |                     |        |         |        |
| FR         | Gasoline              | 167                  | 2.4                   | 0.033               |        |         |        |
| FR         | Gasoline              | 1,020                | 12.2                  |                     |        |         |        |
| FR         | Gasoline              | 262                  | 4.4                   |                     |        |         |        |
| FR         | Gasoline              | 1,020                | 9.8                   |                     |        |         |        |
| FR         | Gasoline              | 0.0238               | 1.6                   |                     |        | 2.4     | 1.1    |
| FR         | Gasoline              | 1,020                | 10                    |                     |        | 15      | 7      |
| FR         | Gasoline              | 1,020                | 6                     |                     |        |         |        |
| FR         | Gasoline              | 1,290                | 4.4                   |                     |        |         |        |
| FR         | Gasoline              | 333                  | 1.3                   |                     |        |         |        |
| FR         | Naphtha               | 833                  | 5                     |                     |        |         |        |
| FR         | Naphtha               | 66.7                 |                       |                     |        | 60      | 24     |
| FR         | Naphtha               | 1,980                | 5.1                   |                     |        | 7.8     | 3.4    |
| FR         | Naphtha               | 1,950                | 6.5                   |                     |        | 22      | 11     |
| FR         | Naphtha               | 2,000                |                       |                     |        | 14      | 6.3    |
| FR         | Naphtha               | 1,140                | 13.4                  |                     |        | 3.6     | 1.5    |
| FR         | Naphtha               | 1,140                | 30                    |                     |        | 8.5     | 3.7    |
| FR         | Naphtha               | 193                  | 13                    |                     |        | 4       | 2      |
| FR         | Naphtha               | 1,950                | 20                    |                     |        | 5.7     | 2.4    |
| FR         | Naphtha               | 1,400                | 22                    |                     |        | 6.4     | 2.8    |
| FR         | Naphtha               | 1,140                | 13                    |                     |        | 3.6     | 1.5    |
| FR         | Naphtha               | 452                  |                       |                     |        | 185     | 75     |
| FR         | Naphtha               | 1,140                | 15                    |                     |        | 4       | 1.7    |
| FR         | Naphtha               | 1,050                | 12                    |                     |        | 18      | 8      |

(continued)

TABLE 4-6. (Continued)

| Tank type*             | Petroleum liquid type | Throughput (Mbbl/yr) | HAP Emissions (lb/yr)        |                     |        |                |
|------------------------|-----------------------|----------------------|------------------------------|---------------------|--------|----------------|
|                        |                       |                      | Benzene                      | Ethylene dichloride | Phenol | Toluene Xylene |
| FR                     | Naphtha               | 1,190                | 16.3                         |                     |        |                |
| FR                     | Naphtha               | 4,810                | 28                           |                     |        | 39 18          |
| FR                     | Naphtha               | 1,140                | 18                           |                     |        | 5.2 2.3        |
| FR                     | Naphtha               | 881                  | 111                          |                     |        | 31 13          |
| FR                     | Naphtha               | 1,400                | 12                           |                     |        | 3.3 1.4        |
| FR                     | Naphtha               | 1,140                | 13.4                         |                     |        | 3.6 1.5        |
| FR                     | Naphtha               | 42.9                 |                              |                     |        | 3.3 1.3        |
| FR                     | Other                 | 219                  | 1                            |                     |        |                |
| FR                     | Other                 | 19                   |                              |                     | 210    |                |
| FR                     | Other                 | 219                  | 0.6                          |                     |        | 0.4            |
| FR                     | Other                 | 11.9                 |                              |                     | 28.1   |                |
| Total emissions by HAP |                       |                      | 533                          | 0.033               | 238    | 471 239        |
| • FIX - Fixed roof     |                       |                      | FR - External floating roof  |                     |        |                |
|                        |                       |                      | IFR - Internal floating roof |                     |        |                |

TABLE 4-7. STORAGE TANK EMISSIONS - REFINERY G

| Tank type* | Petroleum liquid type | Throughput (Mbbbl/yr) | HAP Emissions (lb/yr) |                     |                    |               |             |                |
|------------|-----------------------|-----------------------|-----------------------|---------------------|--------------------|---------------|-------------|----------------|
|            |                       |                       | Benzene               | Ethylene dichloride | Ethylene dibromide | Glycol ethers | Naphthalene | Toluene Xylene |
| FIX        | Distillate fuel       | 2.27                  |                       |                     |                    |               | 6           | 1 1            |
| FIX        | Gasoline              | 0.274                 | 4                     |                     |                    |               |             | 5 1.6          |
| FIX        | Gasoline              | 0.457                 | 5                     |                     |                    |               |             | 6 1.8          |
| FIX        | Jet kerosene          | 471                   |                       |                     |                    |               | 23          |                |
| FIX        | Jet kerosene          | 471                   |                       |                     |                    |               | 23          |                |
| FIX        | Naphtha               | 85.2                  | 8.5                   |                     |                    |               |             | 6.6 2.6        |
| FIX        | Other                 | 0.0833                |                       |                     |                    | 15            |             |                |
| FIX        | Other                 | 15.3                  | 29                    |                     |                    |               | 23          | 9              |
| FR         | Crude                 | 4,890                 | 0.6                   |                     |                    |               | 0.4         | 0.4            |
| FR         | Crude                 | 4,890                 | 0.6                   |                     |                    |               | 0.4         | 0.4            |
| FR         | Crude                 | 4,890                 | 0.6                   |                     |                    |               | 0.4         | 0.4            |
| FR         | Distillate fuel       | 500                   |                       |                     |                    |               | 0.2         | 0.8 0.9        |
| FR         | Distillate fuel       | 2,800                 |                       |                     |                    |               | 0.2         | 0.9            |
| FR         | Gasoline              | 483                   | 11.5                  |                     |                    |               | 10.2        | 2.7            |
| FR         | Gasoline              | 268                   | 11.5                  |                     | 0.000166           |               | 10.2        | 2.7            |
| FR         | Gasoline              | 421                   | 6.4                   |                     |                    |               | 5.7         | 1.6            |
| FR         | Gasoline              | 94                    | 5.8                   |                     |                    |               | 5.2         | 1.4            |
| FR         | Gasoline              | 268                   | 11.5                  | 0.00105             |                    |               | 10.2        | 2.7            |
| FR         | Gasoline              | 268                   | 11.5                  | 0.00105             | 0.000166           |               | 10.2        | 2.7            |
| FR         | Gasoline              | 483                   | 11.5                  |                     |                    |               | 10.2        | 2.7            |
| FR         | Gasoline              | 483                   | 11.5                  |                     |                    |               | 10.2        | 2.7            |
| FR         | Gasoline              | 52.2                  | 5.7                   | 0.000521            | 0.000083           |               | 5.1         | 1.4            |
| FR         | Gasoline              | 52.2                  | 5.7                   | 0.000521            |                    |               | 5.1         | 1.4            |
| FR         | Gasoline              | 483                   | 11.5                  |                     |                    |               | 10.2        | 2.7            |
| FR         | Gasoline              | 241                   |                       | 11.5                |                    |               | 10.2        | 2.7            |
| FR         | Gasoline              | 81                    | 11.3                  |                     |                    |               | 10.1        | 2.7            |
| FR         | Jet kerosene          | 312                   |                       |                     |                    |               | 10          |                |
| FR         | Jet kerosene          | 312                   |                       |                     |                    |               | 10          |                |
| FR         | Naphtha               | 77.4                  |                       | 0.1                 |                    |               | 0.037       | 2.3            |
| FR         | Naphtha               | 2,010                 |                       | 7.3                 |                    |               | 5.7         |                |
| FR         | Naphtha               | 77.4                  |                       | 0.1                 |                    |               | 0.037       |                |
| FR         | Naphtha               | 635                   |                       | 0.2                 |                    |               | 0.1         |                |

(continued)

TABLE 4-7. (Continued)

| Tank type*             | Petroleum liquid type | Throughput (Mbbbl/yr) | HAP Emissions (lb/yr) |                     |                    |               |             |                |
|------------------------|-----------------------|-----------------------|-----------------------|---------------------|--------------------|---------------|-------------|----------------|
|                        |                       |                       | Benzene               | Ethylene dichloride | Ethylene dibromide | Glycol ethers | Naphthalene | Toluene Xylene |
| FR                     | Naphtha               | 2,130                 | 7.3                   |                     |                    |               | 5.7         | 2.3            |
| FR                     | Reformate             | 437                   |                       | 14.5                |                    |               | 18.9        | 4.9            |
| FR                     | Reformate             | 437                   |                       |                     |                    |               | 18.9        | 4.9            |
| FR                     | Reformate             | 1,810                 |                       | 26.7                |                    |               | 35          | 8.9            |
| IFR                    | Naphtha               | 24.3                  | 9.2                   |                     |                    |               | 7.4         | 1.9            |
| IFR                    | Naphtha               | 37.5                  | 9.9                   |                     |                    |               | 7.9         | 2.1            |
| IFR                    | Other                 | 15.3                  | 8.1                   |                     |                    |               | 6.5         | 1.6            |
| Total emissions by HAP |                       |                       | 198                   | 60.4                | 0.000415           | 15            | 72.4        | 265            |
|                        |                       |                       |                       |                     |                    |               |             | 78             |

\*FIX = Fixed roof FR = External floating roof IFR = Internal floating roof

TABLE 4-8. STORAGE TANK EMISSIONS - REFINERY I

| Tank<br>type* | Petroleum<br>liquid<br>type | Throughput<br>(Mbbbl/yr) | HAP Emissions (lb/yr) |          |          |
|---------------|-----------------------------|--------------------------|-----------------------|----------|----------|
|               |                             |                          | Benzene               | Toluene  | Xylene   |
| FIX           | Crude                       |                          | 0.00023               |          |          |
| FIX           | Distillate fuel             |                          | 1.72                  | 0.55     | 0.183    |
| FIX           | Distillate fuel             |                          |                       | 1810     | 1490     |
| FIX           | Distillate fuel             |                          | 0.554                 | 0.17     | 0.0453   |
| FIX           | Distillate fuel             |                          | 0.161                 | 0.0437   | 0.0101   |
| FIX           | Distillate fuel             |                          | 1.2                   | 0.376    | 0.125    |
| FIX           | Distillate fuel             |                          | 0.294                 | 0.0832   | 0.0192   |
| FIX           | Distillate fuel             |                          | 1.11                  | 0.34     | 0.113    |
| FIX           | Distillate fuel             |                          | 1.46                  | 0.507    | 0.169    |
| FIX           | Distillate fuel             |                          | 0.0278                | 3.71     | 4.76     |
| FIX           | Distillate fuel             |                          |                       | 9.97     | 11.8     |
| FIX           | Distillate fuel             |                          | 0.1                   | 0.0286   | 0.00816  |
| FIX           | Distillate fuel             |                          | 0.929                 | 0.271    | 0.0774   |
| FIX           | Distillate fuel             |                          | 4.97                  | 10.6     | 0.0024   |
| FIX           | Distillate fuel             |                          |                       | 13.7     | 9.52     |
| FIX           | Gasoline                    |                          | 6.28                  | 13.4     | 1.97     |
| FIX           | Gasoline                    |                          | 8.77                  | 18       | 2.85     |
| FIX           | Gasoline                    |                          | 0.000144              | 0.000039 | 0.000144 |
| FIX           | Gasoline                    |                          | 9.96                  | 21.4     | 3.48     |
| FIX           | Gasoline                    |                          | 7.54                  | 17.4     | 2.72     |
| FIX           | Gasoline                    |                          | 67.1                  | 154      | 24.6     |
| FIX           | Gasoline                    |                          | 6.71                  | 12.2     | 2.18     |
| FIX           | Gasoline                    |                          | 11.6                  | 26.9     | 4.25     |
| FIX           | Gasoline                    |                          | 15.6                  | 35.6     | 5.66     |
| FIX           | Gasoline                    |                          | 20.2                  | 44.2     | 7.14     |
| FIX           | Gasoline                    |                          | 32.4                  | 72.3     | 11.7     |
| FIX           | Gasoline                    |                          | 13.9                  | 30.8     | 4.94     |
| FIX           | Gasoline                    |                          | 13.8                  | 31.3     | 4.86     |
| FIX           | Jet kerosene                |                          | 92.7                  | 206      | 35.1     |
| FIX           | Jet kerosene                |                          | 51.5                  | 120      | 18.6     |
| FIX           | Jet kerosene                |                          | 129                   | 283      | 50.5     |
| FIX           | Jet kerosene                |                          | 68.6                  | 153      | 24.7     |
| FIX           | Jet kerosene                |                          | 96.2                  | 215      | 34       |

(continued)

TABLE 4-8. (Continued)

| Tank type* | Petroleum liquid type | Throughput (Mbbbl/yr) | HAP Emissions (lb/yr) |          |         |
|------------|-----------------------|-----------------------|-----------------------|----------|---------|
|            |                       |                       | Benzene               | Toluene  | Xylene  |
| FIX        | Jet kerosene          |                       | 152                   | 345      | 61.8    |
| FIX        | Jet kerosene          |                       | 75                    | 159      | 24.3    |
| FIX        | Jet kerosene          |                       | 7.53                  | 16.1     | 2.41    |
| FIX        | Jet kerosene          |                       |                       | 6.04     | 7.86    |
| FIX        | Jet kerosene          |                       |                       | 1.74     | 1.95    |
| FIX        | Jet kerosene          |                       |                       | 3.98     | 5       |
| FIX        | Jet kerosene          |                       |                       | 5.89     | 7.66    |
| FIX        | Jet kerosene          |                       |                       | 5.73     | 7.36    |
| FIX        | Jet naphtha           |                       |                       | 1.63     | 1.86    |
| FIX        | Jet naphtha           |                       |                       | 1.76     | 2.28    |
| FIX        | Jet naphtha           |                       |                       | 1.51     | 1.75    |
| FIX        | Jet naphtha           |                       |                       | 0.968    | 1.11    |
| FIX        | Jet naphtha           |                       |                       | 0.0535   | 0.0585  |
| FIX        | Jet naphtha           |                       |                       | 1.24     | 1.37    |
| FIX        | Jet naphtha           |                       |                       | 306      | 353     |
| FIX        | Jet naphtha           |                       | 0.414                 | 0.118    | 0.0296  |
| FIX        | Naphtha               |                       | 81.4                  | 0.00487  |         |
| FIX        | Other                 |                       |                       | 1.62     | 1.1     |
| FIX        | Other                 |                       | 0.384                 | 50.9     | 58.1    |
| FIX        | Other                 |                       | 0.298                 | 42.2     | 49.4    |
| FIX        | Other                 |                       |                       | 22       | 14.2    |
| FIX        | Other                 |                       | 0.058                 | 7.74     | 8.58    |
| FIX        | Other                 |                       | 0.4                   | 53.2     | 61.5    |
| FIX        | Other                 |                       |                       | 13.7     | 8.87    |
| FIX        | Other                 |                       | 0.0349                | 0.093    | 0.00233 |
| FIX        | Other                 |                       | 0.306                 | 0.0996   | 0.0312  |
| FIX        | Slop oil              |                       | 0.357                 |          |         |
| FIX        | Toluene               |                       |                       | 730      |         |
| FIX        | Toluene               |                       |                       | 1450     |         |
| FIX        | Toluene               |                       |                       | 143      |         |
| FIX        | Toluene               |                       |                       | 1490     |         |
| FIX        | Xylene                |                       |                       |          | 64      |
| FR         | Crude                 |                       | 0.00122               | 0.000406 |         |

(continued)

TABLE 4-8. (Continued)

| Tank<br>type* | Petroleum<br>liquid<br>type | Throughput<br>(Mbbl/yr) | HAP Emissions (lb/yr) |         |         |
|---------------|-----------------------------|-------------------------|-----------------------|---------|---------|
|               |                             |                         | Benzene               | Toluene | Xylene  |
| FR            | Crude                       |                         | 0.00211               |         |         |
| FR            | Crude                       |                         | 0.00525               |         |         |
| FR            | Crude                       |                         | 0.000618              | 0.00206 |         |
| FR            | Crude                       |                         | 0.00308               |         |         |
| FR            | Crude                       |                         | 0.00602               |         |         |
| FR            | Distillate fuel             |                         | 0.0295                | 0.00661 | 0.0295  |
| FR            | Distillate fuel             |                         | 0.0721                | 0.0227  | 0.00802 |
| FR            | Distillate fuel             |                         | 0.00423               | 0.00117 | 0.00027 |
| FR            | Distillate fuel             |                         | 0.0137                | 0.00395 | 0.00105 |
| FR            | Distillate fuel             |                         | 0.0746                | 0.0232  | 0.00877 |
| FR            | Gasoline                    |                         | 60.7                  | 125     | 19.3    |
| FR            | Gasoline                    |                         | 197                   | 457     | 90.6    |
| FR            | Gasoline                    |                         | 100                   | 231     | 36.6    |
| FR            | Gasoline                    |                         | 94.9                  | 207     | 31.4    |
| FR            | Gasoline                    |                         | 105                   | 240     | 36.6    |
| FR            | Gasoline                    |                         |                       | 0.856   | 0.988   |
| FR            | Gasoline                    |                         | 99.4                  | 218     | 34.2    |
| FR            | Gasoline                    |                         | 101                   | 214     | 31.3    |
| FR            | Gasoline                    |                         | 38.2                  | 79.1    | 12.2    |
| FR            | Gasoline                    |                         | 8.2                   | 16.6    | 2.55    |
| FR            | Gasoline                    |                         | 118                   | 250     | 37.6    |
| FR            | Gasoline                    |                         | 44.7                  | 93.2    | 15      |
| FR            | Gasoline                    |                         | 109                   | 244     | 39.8    |
| FR            | Gasoline                    |                         | 221                   | 35      |         |
| FR            | Gasoline                    |                         | 64.6                  | 137     | 21.5    |
| FR            | Gasoline                    |                         | 90.6                  | 201     | 32.1    |
| FR            | Gasoline                    |                         | 24.9                  | 58      | 9.16    |
| FR            | Gasoline                    |                         | 87.1                  | 197     | 30.6    |
| FR            | Gasoline                    |                         | 106                   | 230     | 33.9    |
| FR            | Gasoline                    |                         | 57.6                  | 13      | 18.2    |
| FR            | Jet kerosene                |                         | 0.382                 | 0.819   | 0.123   |

(continued)

TABLE 4-8. (Continued)

| Tank<br>type <sup>a</sup> | Petroleum<br>liquid<br>type | Throughput<br>(Mbbl/yr) | HAP Emissions (lb/yr) |          |        |
|---------------------------|-----------------------------|-------------------------|-----------------------|----------|--------|
|                           |                             |                         | Benzene               | Toluene  | Xylene |
| FR                        | Jet kerosene                |                         | 4.93                  | 10.4     | 1.52   |
| FR                        | Jet kerosene                |                         |                       | 12.7     | 14.7   |
| FR                        | Jet kerosene                |                         |                       | 13.7     | 15.9   |
| FR                        | Jet kerosene                |                         |                       | 0.0416   | 20     |
| FR                        | Jet kerosene                |                         | 0.0341                | 9.59     | 11.1   |
| FR                        | Jet naphtha                 |                         |                       | 2.41     | 2.78   |
| FR                        | Jet naphtha                 |                         |                       | 12.4     | 15.8   |
| FR                        | Jet naphtha                 |                         |                       | 0.0161   | 0.0191 |
| FR                        | Jet naphtha                 |                         |                       | 0.189    | 0.206  |
| FR                        | Jet naphtha                 |                         |                       | 3.1      | 3.57   |
| FR                        | Jet naphtha                 |                         |                       | 16.7     | 21.3   |
| FR                        | Jet naphtha                 |                         |                       | 24.5     | 28.2   |
| FR                        | Jet naphtha                 |                         |                       | 49.3     | 63.9   |
| FR                        | Jet naphtha                 |                         |                       | 15       | 17.3   |
| FR                        | Jet naphtha                 |                         |                       | 2.2      | 2.39   |
| FR                        | Jet naphtha                 |                         |                       | 2.25     | 0.264  |
| FR                        | Naphtha                     |                         | 107                   | 0.00594  |        |
| FR                        | Naphtha                     |                         | 0.212                 | 27.8     | 0.212  |
| FR                        | Other                       |                         | 50                    | 106      | 16.7   |
| FR                        | Other                       |                         | 0.00019               |          |        |
| FR                        | Other                       |                         | 0.000063              |          |        |
| FR                        | Other                       |                         | 17.3                  | 36.4     | 5.4    |
| FR                        | Other                       |                         |                       | 1.86     | 2.15   |
| FR                        | Other                       |                         | 33.7                  | 71       | 10.5   |
| FR                        | Other                       |                         | 0.000402              | 0.000134 |        |
| FR                        | Other                       |                         |                       | 12       | 15.5   |
| FR                        | Other                       |                         |                       | 1.89     | 2.23   |
| FR                        | Other                       |                         | 11.5                  | 24.5     | 3.61   |
| FR                        | Other                       |                         | 0.000108              |          |        |
| FR                        | Other                       |                         | 19.7                  | 41.4     | 6.17   |
| FR                        | Other                       |                         | 0.00619               | 0.86     | 0.994  |
| FR                        | Other                       |                         |                       | 569      |        |
| FR                        | Other                       |                         | 0.0141                | 1.87     | 2.21   |

(continued)

TABLE 4-8. (Continued)

| Tank<br>type*          | Petroleum<br>liquid<br>type | Throughput<br>(Mbbl/yr)      | HAP Emissions (lb/yr) |         |        |
|------------------------|-----------------------------|------------------------------|-----------------------|---------|--------|
|                        |                             |                              | Benzene               | Toluene | Xylene |
| FR                     | Other                       |                              |                       | 2.02    | 1.5    |
| FR                     | Slop oil                    |                              | 0.000792              |         |        |
| FR                     | Slop oil                    |                              | 0.000803              |         |        |
| FR                     | Slop oil                    |                              | 0.00098               |         |        |
| FR                     | Slop oil                    |                              | 0.00101               |         |        |
| FR                     | Slop oil                    |                              | 0.000768              |         |        |
| FR                     | Slop oil                    |                              | 0.000451              |         |        |
| FR                     | Slop oil                    |                              | 0.00137               |         |        |
| FR                     | Slop oil                    |                              | 0.00736               |         |        |
| FR                     | Slop oil                    |                              | 0.000866              |         |        |
| FR                     | Slop oil                    |                              | 0.00895               |         |        |
| FR                     | Slop oil                    |                              | 0.000858              |         |        |
| FR                     | Slop oil                    |                              | 0.00076               |         |        |
| Total emissions by HAP |                             |                              | 2,960                 | 12,500  | 3,320  |
| *FIX - Fixed roof      | FR - External floating roof | IFR - Internal floating roof |                       |         |        |

TABLE 4-9. STORAGE TANK EMISSIONS - REFINERY J

| Tank type*             | Petrolium liquid type | Throughput (Mbbbl/yr)** | HAP Emissions (lb/yr) |                     |                    |             |         |
|------------------------|-----------------------|-------------------------|-----------------------|---------------------|--------------------|-------------|---------|
|                        |                       |                         | Benzene               | Ethylene dichloride | Ethylene dibromide | Naphthalene | Toluene |
| FIX                    | Gasoline              | 1                       |                       |                     |                    |             | 1.2     |
| FIX                    | Gasoline              | 4.8                     |                       |                     |                    |             | 1.3     |
| FIX                    | Gasoline              | 0.59                    |                       |                     |                    |             | 0.24    |
| FIX                    | Gasoline              | 0.44                    |                       |                     |                    |             | 0.51    |
| FIX                    | Gasoline              |                         |                       |                     |                    |             | 0.04    |
| FIX                    | Gasoline              | 1.5                     |                       |                     | 0.00054            |             | 0.74    |
| FIX                    | Gasoline              | 8                       |                       |                     | 0.003              |             | 4.1     |
| FIX                    | Gasoline              | 5.6                     |                       |                     | 0.0021             |             | 2.9     |
| FR                     | Gasoline              | 6.7                     |                       |                     | 0.012              |             | 7.2     |
| FR                     | Gasoline              | 7.8                     |                       |                     |                    |             | 8       |
| FR                     | Gasoline              | 8.1                     |                       |                     | 0.0068             |             | 8.4     |
| FR                     | Gasoline              | 9.8                     |                       |                     | 0.018              |             | 10.7    |
| FR                     | Gasoline              | 7.3                     |                       |                     |                    |             | 7.5     |
| FR                     | Gasoline              | 7.6                     |                       | 0.012               | 0.002              |             | 7.7     |
| FR                     | Gasoline              | 0.42                    |                       |                     |                    |             | 0.49    |
| FR                     | Gasoline              | 3.5                     |                       |                     |                    |             | 0.84    |
| FR                     | Gasoline              | 3.5                     |                       |                     |                    | 0.000072    | 0.85    |
| FR                     | Gasoline              | 1.3                     |                       |                     |                    | 0.000072    | 2.8     |
| FR                     | Gasoline              | 1.5                     |                       |                     |                    | 0.0000058   | 2.6     |
| FR                     | Gasoline              | 1.3                     |                       |                     |                    |             | 2.7     |
| FR                     | Gasoline              | 9                       |                       |                     |                    |             | 9.2     |
| FR                     | Gasoline              | 8.2                     |                       |                     | 0.015              |             | 9.1     |
| FR                     | Gasoline              | 9.3                     |                       |                     |                    |             | 9.5     |
| FR                     | Gasoline              |                         |                       |                     |                    |             | 0.01    |
| FR                     | Gasoline              | 7.7                     |                       |                     |                    |             | 7.9     |
| IFR                    | Gasoline              | 6.8                     |                       |                     |                    | 0.0073      | 9.4     |
| IFR                    | Gasoline              | 6.6                     |                       |                     |                    | 0.0072      | 9.2     |
| IFR                    | Gasoline              | 11                      |                       |                     |                    |             | 0.59    |
| IFR                    | Gasoline              | 9.3                     |                       |                     |                    |             | 3       |
| IFR                    | Gasoline              | 4.1                     |                       |                     |                    | 0.0091      | 3.5     |
| IFR                    | Gasoline              | 4.1                     |                       |                     |                    | 0.0093      | 3.6     |
| IFR                    | Gasoline              | 10.4                    |                       |                     |                    | 0.0039      | 5.3     |
| IFR                    | Gasoline              | 7.4                     |                       | 0.02                | 0.002              | 0.018       | 7.6     |
| IFR                    | Gasoline              | 9.3                     |                       |                     |                    | 0.017       | 10      |
| IFR                    | Gasoline              | 11                      |                       |                     |                    | 0.015       | 11.3    |
| IFR                    | Gasoline              | 3.8                     |                       | 0.0063              | 0.001              | 0.0092      | 3.9     |
| IFR                    | Gasoline              | 3.7                     |                       |                     |                    | 0.0066      | 3.9     |
| IFR                    | Gasoline              | 0.68                    |                       | 0.0011              | 0.00018            | 0.0017      | 0.69    |
| IFR                    | Gasoline              | 3.1                     |                       |                     |                    |             | 3.2     |
| IFR                    | Gasoline              | 2.9                     |                       |                     |                    |             | 2.9     |
| IFR                    | Gasoline              | 3.6                     |                       |                     |                    | 0.0065      | 3.9     |
| Total emissions by HAP |                       |                         | 213                   | 0.0394              | 0.00518            | 0.186       | 188     |
|                        |                       |                         |                       |                     |                    |             | 84      |

\*FIX = Fixed roof FR = External floating roof IFR = Internal floating roof

\*\* Confidential for this refinery.

TABLE 4-10. STORAGE TANK EMISSIONS - REFINERY K

| Tank<br>type* | Petroleum<br>liquid<br>type | Throughput<br>(Mbbl/yr) | HAP Emissions (lb/yr) |            |             |            |         |        |
|---------------|-----------------------------|-------------------------|-----------------------|------------|-------------|------------|---------|--------|
|               |                             |                         | Benzene               | Cresol     | Naphthalene | Phenol     | Toluene | Xylene |
| FIX           | Crude                       |                         | 0.146                 | 0.000588   | 0.0942      | 0.000235   | 0.594   | 0.972  |
| FIX           | Gasoline                    |                         | 48.5                  | 0.0274     |             | 0.0157     | 158     | 177    |
| FIX           | Jet kerosene                |                         | 0.126                 | 0.000529   | 0.0227      | 0.0000991  | 0.253   | 0.299  |
| FIX           | Other                       |                         | 0.00104               | 0.0000634  | 0.00592     | 0.00000458 | 0.0044  | 0.0131 |
| FIX           | Other                       |                         | 0.000131              | 0.000008   | 0.000746    | 0.0000057  | 0.0005  | 0.0016 |
| FR            | Crude                       |                         | 0.239                 | 0.000964   | 0.155       | 0.000386   | 0.975   | 1.6    |
| FR            | Crude                       |                         | 0.435                 | 0.00176    | 0.281       | 0.000702   | 1.78    | 2.9    |
| FR            | Crude                       |                         | 0.645                 | 0.00261    | 0.417       | 0.00104    | 2.64    | 4.31   |
| FR            | Crude                       |                         | 1.006                 | 0.00406    | 0.65        | 0.00162    | 4.11    | 6.72   |
| FR            | Crude                       |                         | 2.003                 | 0.00807    | 1.29        | 0.00323    | 8.16    | 13.4   |
| FR            | Crude                       |                         | 0.0958                | 0.000387   | 0.062       | 0.000154   | 0.391   | 0.64   |
| FR            | Crude                       |                         | 0.103                 | 0.000419   | 0.0672      | 0.000167   | 0.424   | 0.694  |
| FR            | Crude                       |                         | 1.95                  | 0.00786    | 1.26        | 0.00315    | 7.95    | 13     |
| FR            | Crude                       |                         | 2.74                  | 0.011      | 1.77        | 0.00442    | 11.2    | 18.3   |
| FR            | Crude                       |                         | 1.608                 | 0.0065     | 1.04        | 0.0026     | 6.57    | 10.8   |
| FR            | Crude                       |                         | 1.49                  | 0.00599    | 0.961       | 0.00239    | 6.06    | 9.92   |
| FR            | Crude                       |                         | 1.108                 | 0.00447    | 0.717       | 0.00179    | 4.53    | 7.39   |
| FR            | Crude                       |                         | 0.208                 | 0.000838   | 0.134       | 0.000335   | 0.847   | 1.39   |
| FR            | Crude                       |                         | 0.861                 | 0.00348    | 0.557       | 0.00139    | 3.52    | 5.75   |
| FR            | Distillate fuel             |                         | 0.00018752            | 0.00195    | 0           | 0.000238   | 0       | 0.0003 |
| FR            | Distillate fuel             |                         | 0.000346              | 0.00357    | 0           | 0.000438   | 0       | 0.0006 |
| FR            | Distillate fuel             |                         | 0.000354              | 0.00366    | 0           | 0.000448   | 0       | 0.0007 |
| FR            | Distillate fuel             |                         | 0.000888              | 0.0092     | 0           | 0.00112    | 0       | 0.0017 |
| FR            | Distillate fuel             |                         | 0.00049599            | 0.00514    | 0           | 0.000628   | 0       | 0.0009 |
| FR            | Distillate fuel             |                         | 0.00205               | 0.0212     |             | 0.0026     |         | 0.0040 |
| FR            | Gasoline                    |                         | 0.00641               | 0.00000362 |             | 0.00000207 | 0.0209  | 0.0234 |
| FR            | Gasoline                    |                         | 0.991                 | 0.00056    |             | 0.00032    | 3.23    | 3.62   |
| FR            | Gasoline                    |                         | 53.9                  | 0.0305     |             | 0.0174     | 176     | 197    |
| FR            | Gasoline                    |                         | 0.0357                | 0          | 0           | 0          | 24.9    | 115    |
| FR            | Gasoline                    |                         | 0.0334                | 0          | 0           | 0          | 23.4    | 108    |
| FR            | Gasoline                    |                         | 0.0269                | 0          | 0           | 0          | 18.8    | 86.5   |
| FR            | Gasoline                    |                         | 49.7                  | 0.0827     | 0           | 0.0531     | 138     | 96.3   |

(continued)

TABLE 4-10. (Continued)

| Tank type* | Petroleum liquid type | Throughput (Mbbbl/yr) | HAP Emissions (lb/yr) |          |             |           |         |
|------------|-----------------------|-----------------------|-----------------------|----------|-------------|-----------|---------|
|            |                       |                       | Benzene               | Cresol   | Naphthalene | Phenol    | Toluene |
| FR         | Gasoline              |                       | 21.2                  | 0.012    | 0           | 0.00687   | 69.4    |
| FR         | Gasoline              |                       | 57.1                  | 0.0323   | 0           | 0.0185    | 187     |
| FR         | Gasoline              |                       | 3.57                  | 0.00202  | 0           | 0.00115   | 11.6    |
| FR         | Gasoline              |                       | 51.6                  | 0.0291   | 0           | 0.0167    | 169     |
| FR         | Gasoline              |                       | 51.8                  | 0.0293   | 0           | 0.0167    | 169     |
| FR         | Gasoline              |                       | 18.3                  | 0.0103   | 0           | 0.0059    | 59.6    |
| FR         | Gasoline              |                       | 54.5                  | 0.0308   | 0           | 0.0176    | 178     |
| FR         | Gasoline              |                       | 0.216                 | 0.000122 |             | 0.0000698 | 0.706   |
| FR         | Gasoline              |                       | 19.8                  | 0.0112   | 0           | 0.00641   | 64.9    |
| FR         | Gasoline              |                       | 29.3                  | 0.0166   |             | 0.00946   | 95.7    |
| FR         | Gasoline              |                       | 40.07                 | 0.0227   | 0           | 0.013     | 131     |
| FR         | Gasoline              |                       | 42.6                  | 0.0241   | 0           | 0.0137    | 139     |
| FR         | Gasoline              |                       | 15.6                  | 0.00881  | 0           | 0.00503   | 50.9    |
| FR         | Gasoline              |                       | 15.9                  | 0.00898  | 0           | 0.00513   | 51.9    |
| FR         | Gasoline              |                       | 3.26                  | 0.00184  | 0           | 0.00105   | 10.6    |
| FR         | Gasoline              |                       | 18.4                  | 0.0104   | 0           | 0.00593   | 60      |
| FR         | Gasoline              |                       | 3.801                 | 0.00215  | 0           | 0.00123   | 12.4    |
| FR         | Gasoline              |                       | 4.44                  | 0.00251  | 0           | 0.00143   | 14.5    |
| FR         | Gasoline              |                       | 17.6                  | 0.00993  | 0           | 0.00568   | 57.4    |
| FR         | Gasoline              |                       | 21.6                  | 0.0122   | 0           | 0.00699   | 70.7    |
| FR         | Gasoline              |                       | 18.2                  | 0.0103   |             | 0.00587   | 59.4    |
| FR         | Gasoline              |                       | 11.9                  | 0.00674  | 0           | 0.00385   | 38.9    |
| FR         | Gasoline              |                       | 1.32                  | 0.000746 |             | 0.000426  | 4.31    |
| FR         | Gasoline              |                       | 1.32                  | 0.000746 |             | 0.000426  | 4.31    |
| FR         | Gasoline              |                       | 1.7                   | 0.000959 |             | 0.000548  | 5.55    |
| FR         | Jet kerosene          |                       | 3.15                  | 0.0133   | 0.569       | 0.00249   | 6.34    |
| FR         | Jet kerosene          |                       | 0.131                 | 0.011    | 1.04        | 0.00106   | 0       |
| FR         | Jet kerosene          |                       | 0.137                 | 0.0115   | 1.09        | 0.00111   | 0       |
| FR         | Jet kerosene          |                       | 0.107                 | 0.00896  | 0.848       | 0.000861  | 0       |
| FR         | Jet kerosene          |                       | 0.0475                | 0.00399  | 0.377       | 0.000383  | 0       |
| FR         | Jet kerosene          |                       | 0.268                 | 0.0225   | 2.12        | 0.00216   | 0       |
| FR         | Jet kerosene          |                       | 0.264                 | 0.0222   | 2.1         | 0.00214   | 0       |

(continued)

TABLE 4-10. (Continued)

| Tank type* | Petroleum liquid type | Throughput (Mbbbl/yr) | HAP Emissions (lb/yr) |         |             |           |         |        |
|------------|-----------------------|-----------------------|-----------------------|---------|-------------|-----------|---------|--------|
|            |                       |                       | Benzene               | Cresol  | Naphthalene | Phenol    | Toluene | Xylene |
| FR         | Jet kerosene          |                       | 2.2                   | 0.00923 | 0.396       | 0.00173   | 4.42    | 5.23   |
| FR         | Jet kerosene          |                       | 0.073                 | 0.00615 | 0.582       | 0.000592  | 0       | 0.441  |
| FR         | Jet kerosene          |                       | 0.185                 | 0.0155  | 1.47        | 0.00149   | 0       | 1.11   |
| FR         | Jet kerosene          |                       | 0.177                 | 0.0149  | 1.41        | 0.00143   | 0       | 1.07   |
| FR         | Jet kerosene          |                       | 0.0982                | 0.00825 | 0.781       | 0.000793  | 0       | 0.592  |
| FR         | Jet kerosene          |                       | 0.0223                | 0.00187 | 0.177       | 0.000181  | 0       | 0.134  |
| FR         | Jet kerosene          |                       | 2.1                   | 0.00884 | 0.38        | 0.00166   | 4.22    | 5      |
| FR         | Jet naphtha           |                       | 0                     | 0.0262  | 0.429       | 0.0139    | 0.746   | 2.45   |
| FR         | Jet naphtha           |                       | 0                     | 0.0706  | 1.16        | 0.0375    | 2.007   | 6.6    |
| FR         | Jet naphtha           |                       | 0                     | 0.0737  | 1.21        | 0.0391    | 2.1     | 6.89   |
| FR         | Jet naphtha           |                       | 0                     | 0.0761  | 1.25        | 0.0404    | 2.17    | 7.12   |
| FR         | Jet naphtha           |                       | 0                     | 0.623   | 10.2        | 0.331     | 17.8    | 58.3   |
| FR         | Other                 |                       | 0.121                 | 0.00734 | 0.685       | 0.00053   | 0.515   | 1.52   |
| FR         | Other                 |                       | 0.0366                | 0.00223 | 0.208       | 0.000161  | 0.157   | 0.461  |
| FR         | Other                 |                       | 0.171                 | 0.0104  | 0.968       | 0.00075   | 0.728   | 2.14   |
| FR         | Other                 |                       | 0.177                 | 0.0108  | 1           | 0.000777  | 0.755   | 2.22   |
| FR         | Other                 |                       | 5.88                  | 0       | 0.667       | 0         | 31.1    | 40.5   |
| FR         | Other                 |                       | 0.179                 | 0.0109  | 1.02        | 0.000787  | 0.765   | 2.26   |
| FR         | Other                 |                       | 0.232                 | 0.0141  | 1.31        | 0.00102   | 0.99    | 2.92   |
| FR         | Other                 |                       | 0.0743                | 0.00452 | 0.421       | 0.000326  | 0.317   | 0.934  |
| FR         | Other                 |                       | 0.0194                | 0.00119 | 0.11        | 0.0000853 | 0.0829  | 0.24   |
| FR         | Other                 |                       | 1.23                  | 0.0751  | 7           | 0.00542   | 5.26    | 15.5   |
| FR         | Other                 |                       | 0.0404                | 0.00246 | 0.23        | 0.000178  | 0.172   | 0.509  |
| FR         | Other                 |                       | 0.661                 | 0.0402  | 3.75        | 0.0029    | 2.82    | 8.31   |
| FR         | Other                 |                       | 0.679                 | 0.0413  | 3.85        | 0.00298   | 2.9     | 8.53   |
| FR         | Other                 |                       | 0.151                 | 0.00919 | 0.857       | 0.000663  | 0.645   | 1.89   |
| FR         | Other                 |                       | 0.151                 | 0.00919 | 0.857       | 0.000663  | 0.645   | 1.9    |
| FR         | Other                 |                       | 0.152                 | 0.00924 | 0.862       | 0.000666  | 0.645   | 1.91   |
| FR         | Other                 |                       | 5.06                  | 0.308   | 28.8        | 0.0222    | 21.6    | 63.7   |
| FR         | Other                 |                       | 7.2                   | 0       | 0.816       | 0         | 38      | 49.6   |
| FR         | Other                 |                       | 6.57                  | 0       | 0.745       | 0         | 34.7    | 45.3   |
| FR         | Other                 |                       | 7.9                   | 0       | 0.896       | 0         | 41.7    | 54.5   |

(continued)

TABLE 4-10. (Continued)

| Tank type*             | Petroleum liquid type | Throughput (Mbbl/yr) | HAP Emissions (lb/yr) |            |             |            |         |        |
|------------------------|-----------------------|----------------------|-----------------------|------------|-------------|------------|---------|--------|
|                        |                       |                      | Benzene               | Cresol     | Naphthalene | Phenol     | Toluene | Xylene |
| FR                     | Other                 |                      | 0.634                 | 0.0386     | 3.6         | 0.00279    | 2.71    | 7.98   |
| FR                     | Other                 |                      | 0.139                 | 0.00848    | 0.79        | 0.000611   | 0.594   | 1.75   |
| FR                     | Other                 |                      | 0.121                 | 0.00736    | 0.687       | 0.000531   | 0.516   | 1.52   |
| FR                     | Other                 |                      | 0.121                 | 0.00734    | 0.685       | 0.000531   | 0.515   | 1.52   |
| FR                     | Other                 |                      | 0.121                 | 0.00736    | 0.687       | 0.000531   | 0.516   | 1.52   |
| FR                     | Other                 |                      | 0.122                 | 0.00741    | 0.692       | 0.000536   | 0.52    | 1.54   |
| FR                     | Other                 |                      | 0.122                 | 0.00741    | 0.692       | 0.000536   | 0.52    | 1.54   |
| FR                     | Other                 |                      | 0.122                 | 0.00741    | 0.692       | 0.000536   | 0.52    | 1.54   |
| FR                     | Other                 |                      | 0.122                 | 0.00741    | 0.692       | 0.000536   | 0.52    | 1.54   |
| FR                     | Other                 |                      | 0.000141              | 0.00000857 | 0.000799    | 0.00000061 | 0.0006  | 0.0017 |
| FR                     | Other                 |                      | 0.106                 | 0.00646    | 0.603       | 0.000467   | 0.454   | 1.33   |
| FR                     | Other                 |                      | 0.101                 | 0.00613    | 0.572       | 0.000443   | 0.43    | 1.26   |
| FR                     | Other                 |                      | 0.00548               | 0.000334   | 0.0311      | 0.0000241  | 0.0234  | 0.069  |
| FR                     | Other                 |                      | 0.216                 | 0.0131     | 1.22        | 0.000948   | 0.921   | 2.71   |
| FR                     | Other                 |                      | 1.23                  |            | 0.14        |            | 6.5     | 8.48   |
| FR                     | Other                 |                      | 0.129                 | 0.00787    | 0.734       | 0.000568   | 0.552   | 1.62   |
| FX                     | Crude                 |                      | 0.121                 | 0.000488   | 0.0782      | 0.000195   | 0.493   | 0.807  |
| FX                     | Distillate fuel       |                      | 0.000171              | 0.00177    |             | 0.000216   |         | 0.0003 |
| FX                     | Gasoline              |                      | 7.02                  |            | 0.797       |            | 37.1    | 48.4   |
| FX                     | Gasoline              |                      | 55.1                  | 0.0311     |             | 0.0178     | 180     | 201    |
| FX                     | Gasoline              |                      | 54.6                  | 0.0309     |             | 0.0176     | 178     | 199    |
| FX                     | Jet kerosene          |                      | 0.918                 | 0.00386    | 0.166       | 0.000724   | 1.84    | 2.18   |
| FX                     | Other                 |                      | 0.00112               | 0.0000682  | 0.00636     | 0.00000492 | 0.0047  | 0.0141 |
| Total emissions by HAP |                       |                      | 860                   | 2.33       | 106         | 0.852      | 2,960   | 3,700  |

\*FIX = Fixed roof    FR = External floating roof    IFR = Internal floating roof

TABLE 4-11. REPORTED NUMBER OF TANKS BY PETROLEUM LIQUID TYPE

| Petroleum liquid type            | Tank Type  |                        |                        | Total |
|----------------------------------|------------|------------------------|------------------------|-------|
|                                  | Fixed roof | External floating roof | Internal floating roof |       |
| Alkylate                         | -          | 1                      | -                      | 1     |
| Carbon tetrachloride             | -          | -                      | -                      | 1     |
| Curde                            | 18         | 37                     | 2                      | 57    |
| Diesel/distillate fuel           | 16         | 1.3                    | -                      | 29    |
| Gasoline                         | 28         | 125                    | 22                     | 175   |
| Jet/kerosene                     | 18         | 26                     | 2                      | 46    |
| Jet naphththa                    | 8          | 19                     | -                      | 27    |
| Naphtha                          | 2          | 30                     | 3                      | 35    |
| Others                           | 24         | 59                     | 1                      | 84    |
| Reformate                        | -          | 6                      | -                      | 6     |
| Residual fuel oil                | -          | 3                      | -                      | 3     |
| Slop oil                         | 1          | 15                     | 1                      | 17    |
| Toluene                          | 4          | 1                      | -                      | 5     |
| Xylene                           | 1          | -                      | -                      | 1     |
| Total                            | 121        | 335                    | 31                     | 487   |
| Percent of total number of tanks | 24.8       | 68.8                   | 6.4                    |       |

TABLE 4-12. TANK EMISSION FACTORS FOR STORAGE TANKS

| Tank Emission Factors by HAP (lb/yr per 1000 Bbl/sd refinery process capacity)  |                       |                        |      |                 |              |        |             |                     |                    |               |               |             |         |         |         |
|---|-----------------------|------------------------|------|-----------------|--------------|--------|-------------|---------------------|--------------------|---------------|---------------|-------------|---------|---------|---------|
| Tank type*  | Petroleum liquid type | Carbon tetra- chloride |      | Chloro- benzene | Chloro- form | Cresol | 1,4-Dioxane | Ethylene dichloride | Ethylene dibromide | Glycol ethers | Naph- thalene | Phenol      | Styrene | Toluene | Xylene  |
|   |                       |                        |      |                 |              |        |             |                     |                    |               |               |             |         |         |         |
| FIX   | Carbon tetrachloride  |                        | 0.99 |                 |              |        |             |                     |                    |               |               |             |         |         |         |
| FIX   | Jet kerosene          | 2.54                   | 0.02 | 0.47            | 0.0000395    | 1.72   | 0.03        | 0.2                 |                    | 0.273         | 0.000117      | 0.00000652  | 0.01    | 5.77    | 1.08    |
| FIX   | Others                | 0.098                  |      |                 | 0.00000126   |        |             |                     |                    |               |               | 0.000000443 |         | 0.69    | 0.678   |
| FIX   | Slop oil              | 0.00246                |      |                 |              |        |             |                     |                    |               |               |             |         |         |         |
| FIX   | Crude                 | 0.324                  |      |                 | 0.00000969   |        |             |                     |                    |               | 0.00155       | 0.00000176  |         | 0.443   | 0.291   |
| FIX   | Distillate fuel       | 0.118                  | 0.49 | 3.17            | 0.0298       | 15.9   | 0.45        | 1                   |                    |               | 0.14          | 0.0595      | 0.35    | 5.85    | 4.84    |
| FIX   | Gasoline              | 0.903                  |      |                 | 0.000805     |        |             |                     |                    |               | 0.00316       | 0.00046     |         | 2.32    | 1.57    |
| FIX   | Jet naphtha           | 0.00286                |      |                 |              |        |             |                     |                    |               |               |             |         | 2.16    | 2.5     |
| FIX   | Naphtha               | 0.449                  |      |                 |              |        |             |                     |                    |               |               |             |         | 0.033   | 0.0473  |
| FIX   | Toluene               |                        |      |                 |              |        |             |                     |                    |               |               |             |         | 26.3    |         |
| FIX   | Xylene                |                        |      |                 |              |        |             |                     |                    |               |               |             |         |         | 0.441   |
| FR  | Gasoline              | 3.99                   |      |                 | 0.0037       |        | 0.0175      | 0.0000678           |                    | 0.000432      | 0.00217       |             |         | 8.79    | 6.82    |
| FR  | Jet naphtha           | 0.609                  |      |                 | 0.00784      |        |             |                     |                    | 0.128         | 0.00416       |             |         | 0.426   | 0.504   |
| FR  | Reformate             | 0.988                  |      |                 |              |        | 2.75        |                     |                    | 0.0000264     |               |             |         | 1.87    | 0.499   |
| FR  | Alkylate              | 0.467                  |      |                 |              |        |             |                     |                    |               |               |             |         | 1.35    | 0.00608 |
| FR  | Crude                 | 1.11                   |      |                 | 0.000527     |        |             |                     |                    | 0.0844        | 0.000211      |             |         | 0.185   | 0.248   |
| FR  | Distillate fuel       | 0.0007                 |      |                 | 0.000403     |        |             |                     |                    | 0.00727       | 0.0000493     |             |         | 0.0148  | 0.00597 |
| FR  | distillate fuel       | 0.00832                |      |                 | 0.000507     |        |             |                     |                    | 0.0472        | 0.0000366     |             |         | 0.0355  | 0.105   |
| FR  | Jet kerosene          | 0.0443                 |      |                 | 0.00143      |        | 0.000181    | 0.0000307           |                    | 0.201         | 0.000163      |             |         | 0.167   | 0.173   |
| FR  | Naphtha               | 0.795                  |      |                 |              |        | 0.14        |                     |                    |               |               |             |         | 0.786   | 0.312   |
| FR  | Others                | 0.01                   |      |                 | 0.0057       |        |             |                     |                    | 0.159         | 1.02          |             |         | 1.99    | 0.607   |
| FR  | Slop oil              | 0.0133                 |      |                 |              |        |             |                     |                    |               |               |             |         | 0.0185  | 0.00314 |
| FR  | Toluene               |                        |      |                 |              |        |             |                     |                    |               |               |             |         | 1.38    |         |
| IFR   | Gasoline              | 0.359                  |      |                 |              |        | 0.00000023  | 0.0000222           |                    | 0.000775      |               |             |         | 0.79    | 0.665   |
| IFR   | Slop oil              | 0.0165                 |      |                 |              |        |             |                     |                    |               |               |             |         | 0.0152  | 0.0008  |
| IFR   | Crude                 | 0.07                   | 0.01 | 0.13            |              |        | 0.05        | 0.01                |                    |               |               |             |         | 0.07    | 0.03    |
| IFR   | Jet kerosene          | 0.29                   |      |                 |              |        | 0.00155     | 0.000264            |                    |               |               |             |         | 0.837   | 0.0835  |
| IFR   | Naphtha               | 0.318                  | 0.02 | 0.36            |              | 1.37   | 0.03        | 0.15                |                    |               |               |             | 0.01    | 0.259   | 0.0742  |
| IFR   | Others                | 0.147                  |      |                 |              |        |             |                     |                    |               |               |             |         | 0.118   | 0.0209  |
| FIX = Fixed roof    FR = External floating roof    IFR = Internal floating roof |                       |                        |      |                 |              |        |             |                     |                    |               |               |             |         |         |         |

\*PIX = Fixed roof FR = External floating roof IFR = Internal floating roof

## 5.0 WASTEWATER COLLECTION AND TREATMENT

### 5.1 BACKGROUND INFORMATION

Wastewater is generated by many different petroleum refinery processes and collected by a plant-wide oily water sewer system. It then enters a treatment system in order to remove oils and solids from the water. The specific design of a wastewater treatment system depends on the quantity of wastewater generated, the contaminant concentration, and the desired level of treatment. Some wastewater collection and treatment units may be open to the atmosphere, thus providing a source for hazardous air pollutant (HAP) emissions.

#### 5.1.1 Sources of Refinery Wastewater

Refinery wastewater can be generated through direct contact with organic compounds from refinery processes or through indirect contact with organic compounds. Sources of direct contact wastewater include:<sup>1</sup>

- water used to wash impurities from products or reactants;
- water used to cool or quench vapor streams;
- water used as a carrier for catalyst or caustic solutions;
- water formed as a by-product during reactions;
- condensed steam from jet eductor systems; and
- condensed stripping steam.

Although indirect contact wastewater streams do not come in contact with organic compounds in process equipment, the potential exists for organic contamination of these wastewater streams. Indirect contact wastewater may become contaminated as a result of leaks from heat exchangers, condensers, and pumps.

Direct and indirect contact wastewaters are combined and transported to a wastewater treatment plant.

#### 5.1.2 Description of Wastewater Collection and Treatment Units

A wastewater collection and treatment system is generally comprised of the following units:

- drainage and collection system;
- primary treatment units for oil removal;
- intermediate treatment units for further oil removal; and
- secondary treatment units for final control.

5.1.2.1 Drainage and Collection System. In a typical refinery, wastewater is collected by individual drains that feed into the main process sewer line. Drains are normally open to the atmosphere and provide a venue for HAP's to be emitted. Drains may be dedicated to one piece of equipment or serve several sources. The sewer line carries the wastewater to downstream collection units, such as junction boxes, sumps, and lift stations. Junction boxes serve as a point of convergence for sewer lines, and sumps are typically used for collection and equalization of wastewater flow; both may be open to the atmosphere. Wastewater may then be discharged to a lift station where it is pumped to the treatment system.<sup>2</sup>

Factors affecting HAP emissions from the drainage and collection system include the physical dimensions of each collection unit, climatic factors, physical and chemical characteristics of the HAP's in the wastewater stream, and the stream flow rate.<sup>2</sup>

5.1.2.2 Primary Treatment Units. Primary treatment units serve as the initial means to separate solids and hydrocarbons from wastewater. The most common primary treatment units are oil-water separators and air flotation units.

5.1.2.2.1 Oil-water separators. Separating oil from the water is frequently the first step in wastewater treatment. Oil-water separators use gravity to remove solids and oils contained in the wastewater. Oils and pollutants with specific

gravities less than water float to the top and are skimmed off. Most of the organics contained in the wastewater tend to partition to the oil phase; therefore, the wastewater leaving the oil-water separator is reduced in organic loading.

Emissions from oil-water separators are determined by the characteristics of the wastewater and oil layers, ambient wind speed, and the design characteristics of the separator.<sup>2</sup>

There are several different types of separators. The most common are American Petroleum Institute (API) separators and corrugated plate interceptors (CPI). The API separators use skimmers to remove oil before it enters a quiescent zone, where oil droplets coalesce. Oil droplets are then skimmed from the water surface again at the downstream end of the separator. Corrugated plate interceptors use parallel plates which allow oil droplets to coalesce and form a floating layer that is skimmed from the water.

5.1.2.2.2 Air flotation systems. Air flotation is commonly used to remove free oil, colloidal solids, emulsified oil, and suspended solids after the oil-water separation process. In air flotation systems, bubbles are formed by introducing air directly into the wastewater. The bubbles attach to oils and solids in the wastewater, causing the density of these substances to be less than the density of the liquid. Oils and solids then rise to the top of the flotation system, where they are removed.<sup>1</sup>

Two types of air flotation systems are used in petroleum refineries: dissolved air flotation systems (DAF) and induced air flotation systems (IAF). Both rely on basic air flotation principles for removing oils and solid, but they have a number of mechanical and structural differences. A DAF system is characterized by relatively quiescent flotation, high retention times, and small quantities of air dissolved in the wastewater. An IAF is a more turbulent system, has lower retention times, and uses large quantities of air.<sup>1</sup>

5.1.2.3 Intermediate Treatment Processes. Following oil-water separation and air flotation, wastewater streams can be

further treated by a number of processes, such as coagulation-precipitation, filtration, and equalization.

#### 5.1.2.3.1 Coagulation-precipitation.

Coagulation-precipitation is the process by which chemical coagulants are added to wastewater in order to break oily emulsions. The coagulant reduces the charge repulsion between particles and allows them to combine and form larger particles that settle or float by gravity in a precipitation or sedimentation tank, where they are removed.<sup>1</sup>

5.1.2.3.2 Filtration. Several types of filtration devices have been developed for removing free and emulsified oil from refining wastewaters. These filters range from units using a simple sand medium to those containing media, such as carbon, that exhibit specific affinities for oil.

The filtering medium is usually contained within a basin or tank and is supported by an underdrain system that allows the filtered water to be drawn off, while retaining the filter medium in place.

5.1.2.3.3 Equalization. Flow equalization is used to balance the quantity of wastewater before further treatment. Equalization basins minimize the effects of large periodic discharges on downstream treatment processes. Biological processes, as well as physical-chemical systems, operate more efficiently under regulated flow conditions.<sup>1</sup>

The size of the equalization system depends on the storage capacity required. They are often aerated to maintain aerobic conditions in the wastewater, thus alleviating odor problems.

5.1.2.4 Secondary Treatment Processes. Secondary treatment processes are used to remove dissolved organics through oxidative decomposition by microorganisms. The particular processes used at a refinery are determined by the flow and contaminant characteristics of the wastewater to be treated. Frequently used secondary treatment processes include activated sludge, trickling filters, oxidation ponds, and rotating biological contactors.

Clarifiers are used to remove suspended solids by gravity separation; they always follow biological treatment systems.

## 5.2 METHOD FOR DEVELOPING HAZARDOUS AIR POLLUTION EMISSION FACTORS FOR WASTEWATER COLLECTION AND TREATMENT PROCESSES

Wastewater emission factors were developed for each collection and treatment process by compiling information from California refineries. Correlations were generated between hazardous air pollutant (HAP) emissions from treatment units and the wastewater flow entering each treatment unit.

### 5.2.1 California Refinery Wastewater Collection and Treatment Database

Ideally, HAP emissions from wastewater collection and treatment units should be based on the composition and physical characteristics of a wastewater stream and mass transfer models representing each collection or treatment unit. However, the California Refinery Database does not contain speciated wastewater composition data for individual wastewater streams.

An alternative emissions estimation method was developed based on the average emissions of HAP's reported by California refineries complying with the Air Toxics "Hot Spots" Information and Assessment Act of 1987 (AB 2588). For this approach, the minimum information necessary for calculating emissions from wastewater collection and treatment systems was:

- the specific HAP emissions from each wastewater unit;
- the throughput entering each wastewater unit; and
- the charge capacity of each refinery process unit.

Information from all but two refineries reporting HAP emissions from wastewater collection and treatment units met this criterion.

Table 5-1 presents emissions information from treatment units reported by each refinery. Table 5-2 presents the wastewater flow entering each treatment process reported by the refineries.

### 5.2.2 Development of Hazardous Air Pollutant Emission Factors

The HAP emission factors were generated by dividing the specific HAP emissions reported by each refinery for each wastewater unit by the throughput entering each wastewater unit.

TABLE 5-1. HAZARDOUS AIR POLLUTANT EMISSIONS BY WASTEWATER TREATMENT UNIT (lb/yr)

| Refinery | Pollutant           | Oil-water<br>separators | Air<br>flotation | Bio-<br>treatment | Equalization | Open<br>ponds | Sumps | Misc.<br>treatment | Total  |
|----------|---------------------|-------------------------|------------------|-------------------|--------------|---------------|-------|--------------------|--------|
| A        | Benzene             | 26                      |                  | 719               | 1            | 1,830         |       | 564                | 3,140  |
|          | Toluene             | 84                      |                  | 618               | 2            | 1,180         |       | 908                | 2,792  |
|          | Xylene              | 269                     |                  | 632               | 10           | 1,650         |       | 20                 | 2,581  |
| B        | Benzene             | 412                     | 52               | 3,800             |              |               |       |                    | 4,264  |
|          | Toluene             | 2,390                   | 16               | 9,860             |              |               |       |                    | 12,266 |
|          | Xylene              | 675                     | 18               | 8,140             |              |               |       |                    | 8,833  |
| C        | Benzene             | 1,013                   |                  |                   |              |               |       |                    | 1,013  |
|          | PAH                 | 2.67                    |                  |                   |              |               |       |                    | 2.67   |
|          | Toluene             | 532                     |                  |                   |              |               |       |                    | 532    |
|          | Xylene              | 259                     | 4,961            |                   |              |               |       |                    | 5,220  |
| D        | Benzene             | 6.5                     |                  |                   |              |               |       |                    | 6.5    |
|          | Chlorobenzene       | 0.1                     |                  |                   |              |               |       |                    | 0.1    |
|          | Chloroform          | 0.1                     |                  |                   |              |               |       |                    | 0.1    |
|          | Cresol              | 68.4                    |                  |                   |              |               |       |                    | 68.4   |
|          | 1,4-Dioxane         | 1.7                     |                  |                   |              |               |       |                    | 1.7    |
|          | Ethylene dichloride | 0.1                     |                  |                   |              |               |       |                    | 0.1    |
|          | Ethylene dibromide  | 0.1                     |                  |                   |              |               |       |                    | 0.1    |
|          | Naphthalene         | 8.5                     |                  |                   |              |               |       |                    | 8.5    |
|          | Phenol              | 8.5                     |                  |                   |              |               |       |                    | 8.5    |
|          | Styrene             | 0.1                     |                  |                   |              |               |       |                    | 0.1    |
|          | Toluene             | 5.6                     |                  |                   |              |               |       |                    | 5.6    |
|          | Xylene              | 4.1                     |                  |                   |              |               |       |                    | 4.1    |
| E        | Benzene             | 3.49                    |                  | 242               |              |               |       |                    | 245    |
|          | Naphthalene         | 0.024                   |                  | 1.65              |              |               |       |                    | 1.67   |
|          | Toluene             | 18.7                    |                  | 1,290             |              |               |       |                    | 1,309  |
|          | Xylene              | 6.63                    |                  | 458               |              |               |       |                    | 465    |

(continued)

TABLE 5-1. (Continued)

| Refinery | Pollutant   | Oil-water<br>separators   | Air<br>flotation          | Bio-<br>treatment | Equalization | Open<br>ponds       | Sumps            | Misc.<br>treatment | Total   |
|----------|---|---|---------------------------|-------------------|--------------|---------------------|------------------|--------------------|---|
| F        | Benzene<br>Toluene  | 971<br>2,180  |                           |                   |              |                     |                  |                    | 971<br>2,180  |
| G        | Benzene<br>Toluene<br>Xylene  | 389<br>7.1<br>1   |                           |                   |              |                     |                  | 255<br>255<br>574  | 644<br>262<br>575   |
| H        | Acetaldehyde<br>Anthracene<br>Arsenic<br>Benzene<br>Benzopyrene<br>1,3-Butadiene<br>Formaldehyde<br>Mercury<br>Naphthalene<br>Toluene<br>Xylene | 0.05<br>.3<br>0.0015<br>460<br>.0263<br>78.7<br>1.12<br>0.002<br>0.076<br>33.3<br>120 |                           |                   |              |                     |                  |                    | 0.05<br>.3<br>0.0015<br>460<br>.0263<br>78.7<br>1.12<br>0.002<br>0.076<br>33.3<br>120 |
| I        | Benzene<br>Toluene<br>Xylene  | 687<br>517<br>344   | 6,880<br>11,200<br>15,500 |                   |              | 26.6<br>0.2<br>13.3 | 35.3<br>42<br>28 |                    | 7,629<br>11,759<br>15,885   |
| J        | Toluene   | 2.1   |                           |                   |              |                     |                  |                    | 2.1   |
| K        | Benzene<br>Naphthalene<br>Toluene<br>Xylene   | 367<br>236<br>1,520<br>2,460  |                           |                   |              |                     |                  |                    | 367<br>236<br>1,520<br>2,460  |
|          | TOTAL   | 16,170  | 38,626                    | 25,761            | 13.0         | 4,700               | 105              | 2,576              | 87,950  |

Note: A blank entry indicates no data were reported

TABLE 5-2. FLOW ENTERING TREATMENT UNIT (10<sup>6</sup> gal/yr)

| Refinery | Oil-water<br>separators | Air<br>flotation | Biotreatment | Equalization | Open<br>ponds | Sumps | Miscellaneous<br>treatment |
|----------|-------------------------|------------------|--------------|--------------|---------------|-------|----------------------------|
| A        | 630                     |                  | 0.883        | 0.16         |               |       | 1,220                      |
| B        |                         |                  |              |              |               |       |                            |
| C        | 518                     | 518              |              |              |               |       |                            |
| D        | 2.05                    |                  |              |              |               |       |                            |
| E        | 2.12                    |                  | 2.92         |              |               |       |                            |
| F        | 1,700                   |                  |              |              |               |       |                            |
| G        | 167                     |                  |              |              |               |       | 64.9                       |
| H        |                         |                  |              |              |               |       |                            |
| I        | 1,720                   | 1,720            |              |              |               |       |                            |
| J        | 1,260                   |                  |              |              |               |       |                            |
| K        | 1,270                   |                  |              |              |               |       |                            |

Note: A blank entry indicates no data were reported

Average HAP factors were calculated from the refineries reporting applicable data. Table 5-3 presents the average HAP emission factors (in lb/10<sup>6</sup> gallons).

#### 5.2.3 Total Wastewater Generated from Refineries

The total wastewater generated by refineries nationwide can be estimated using factors developed in a previous study of wastewater generation in refineries.<sup>3</sup> Table 5-4 presents the factors used to calculate total wastewater generated. Table 5-5 presents the total wastewater generated from the California refineries, based on the generation factors and process capacities found in the Oil and Gas Journal.<sup>4</sup>

#### 5.3 DATABASE LIMITATIONS

The wastewater database has some obvious inadequacies. No collection units and only six treatment units were reported by all of the refineries. The only treatment unit reported by all of the refineries was the oil-water separator. However, five refineries did not report any other treatment units after oil-water separation. Only one refinery reported equalization and sumps as part of the treatment system. However, none of them reported the wastewater flow entering open ponds or sumps. Two refineries reported miscellaneous unspecified treatment units. The data on treatment units are lacking.

A total of 23 pollutants were reported. However, 15 of them (1,4-dioxane, styrene, PAH, cresols, chloroform, chlorobenzene, ethylene dichloride, ethylene dibromide, phenol, 1,3-butadiene, arsenic, anthracene, benzopyrene, formaldehyde, and mercury) were reported by only one refinery.

##### 5.3.1 Hazardous Air Pollutant Emission Factors

The HAP emission factors listed in Table 5-3 are not representative of the number and quantity of HAP's reported for each treatment unit because of the lack of flow data. Refineries B, H, and I did not report flows for some of the units they reported emissions from. Therefore, these units were not used to develop the HAP factors. Emissions of several chemicals, such as 1,3-butadiene, were reported, but HAP emission factors

TABLE 5-3. AVERAGE HAZARDOUS AIR POLLUTANT EMISSION FACTORS (lb/10<sup>6</sup> gal)

|                     | Oil-water separator |          |         | Air flotation |          |         | Biotreatment |          |         | Equalization |          |         | Miscellaneous treatment |          |         |
|---------------------|---------------------|----------|---------|---------------|----------|---------|--------------|----------|---------|--------------|----------|---------|-------------------------|----------|---------|
|                     | -- range            | -- value | average | -- range      | -- value | average | -- range     | -- value | average | -- range     | -- value | average | -- range                | -- value | average |
| Benzene             | 0.04                | 3.17     | 1.16    |               | 4        | 82.9    | 814          | 449      |         | 6.25         | 0.46     | 3.93    | 2.19                    |          |         |
| Chlorobenzene       |                     |          | 0.0488  |               |          |         |              |          |         |              |          |         |                         |          |         |
| Chloroform          |                     |          | 0.0488  |               |          |         |              |          |         |              |          |         |                         |          |         |
| Cresol              |                     |          | 33.4    |               |          |         |              |          |         |              |          |         |                         |          |         |
| Ethylene dibromide  |                     |          | 0.0488  |               |          |         |              |          |         |              |          |         |                         |          |         |
| Ethylene dichloride |                     |          | 0.0488  |               |          |         |              |          |         |              |          |         |                         |          |         |
| 1,4-Dioxane         |                     |          | 0.829   |               |          |         |              |          |         |              |          |         |                         |          |         |
| Naphthalene         | 0.011               | 4.15     | 1.45    |               |          |         |              | 0.565    |         |              |          |         |                         |          |         |
| PAH                 |                     |          | 0.0051  |               |          |         |              |          |         |              |          |         |                         |          |         |
| Phenol              |                     |          | 4.15    |               |          |         |              |          |         |              |          |         |                         |          |         |
| Styrene             |                     |          | 0.0488  |               |          |         |              |          |         |              |          |         |                         |          |         |
| Toluene             | 0.002               | 8.82     | 1.78    |               | 6.5      | 442     | 700          | 571      |         | 12.5         | 0.74     | 3.93    | 2.34                    |          |         |
| Xylene              | 0.006               | 3.13     | 1.17    | 9.01          | 9.58     | 157     | 716          | 436      |         | 62.5         | 0.016    | 8.84    | 4.43                    |          |         |

Note: A blank entry indicates no data were reported

TABLE 5-4. WASTEWATER GENERATION FACTORS (gal/bbls)

| Refinery processes                   | Process drains | Cooling tower discharge | Sour water treatment discharge | Chemical treatment | Total |
|--------------------------------------|----------------|-------------------------|--------------------------------|--------------------|-------|
| Crude storage                        | 2.00           |                         |                                |                    | 2.00  |
| Crude desalting                      | 0.002          |                         | 2.1                            |                    | 2.10  |
| Atmospheric distillation             | 0.258          |                         | 0.040                          |                    | 0.298 |
| Gas processing                       | 0.080          | 0.07                    |                                | 3.20               | 3.35  |
| Vacuum distillation                  | 0.835          | 1.33                    | 5.18                           |                    | 7.34  |
| Naphtha hydrosulfurization           | 0.060          | 0.40                    | 1.40                           |                    | 1.86  |
| Catalytic reforming                  | 0.217          | 1.00                    | 0.004                          |                    | 1.22  |
| Isomerization                        | 0.235          | 0.966                   |                                |                    | 1.20  |
| Alkylation                           | 0.413          | 5.72                    |                                | 0.396              | 6.53  |
| Chemical sweetening                  | 1.48           | 1.71                    | 2.04                           | 1.80               | 7.03  |
| Hydrosulfurization                   | 0.104          | 0.765                   | 4.30                           |                    | 5.17  |
| Catalytic cracking                   | 1.12           | 3.02                    | 5.40                           |                    | 9.54  |
| Hydrocracking                        | 0.640          | 0.815                   | 2.97                           |                    | 4.43  |
| Lube oil processing solvent refining | 10.8           | 1.61                    |                                |                    | 12.4  |
| Dewaxing                             | 5.76           | 6.72                    |                                |                    | 12.5  |
| Hydrotreating(lube oil finishing)    | 0.634          | 1.27                    | 1.44                           |                    | 3.34  |
| Visbreaking                          | 0.30           |                         | 0.040                          |                    | 0.340 |
| Coking                               | 3.09           | 2.60                    | 0.707                          |                    | 6.40  |
| Deasphalting                         | 0.30           |                         | 0.04                           |                    | 0.340 |
| Light product storage                | 0.11           |                         |                                |                    | 0.110 |
| Hydrogen production                  | 65.0           | 45.6                    |                                |                    | 111   |
| Light product storage-sludges        | 0.11           |                         |                                |                    | 0.110 |

Generation factors are presented in an article by Finelt, S. and Crump, J.R. Predict Wastewater Generation. Hydrocarbon Processing, August 1977. p.159-166

Note: A blank entry indicates no data were reported

TABLE 5-5. WASTEWATER VOLUMES CALCULATED FROM FACTORS (10<sup>6</sup> gal/yr)

| Refinery | Process drains | Sour water | Chemical treatment | Cooling tower | Wastewater generation per facility |
|----------|----------------|------------|--------------------|---------------|------------------------------------|
| A        | 211            | 569        | 2.34               | 225           | 1,008                              |
| B        | 418            | 862        | 1.17               | 263           | 1,545                              |
| C        | 247            | 630        | 1.64               | 230           | 1,108                              |
| D        | 11.4           | 22.7       | *                  | 3.70          | 37.8                               |
| E        | 421            | 1,049      | 1.31               | 306           | 1,777                              |
| F        | 220            | 336        | *                  | 131           | 687                                |
| G        | 54.8           | 86.9       | *                  | 16.8          | 159                                |
| H        | 235            | 612        | 2.48               | 249           | 1,098                              |
| I        | 228            | 475        | 1.26               | 183           | 887                                |
| J        | 248            | 618        | 1.90               | 241           | 1,110                              |
| K        | 153            | 445        | 1.46               | 156           | 756                                |

Wastewater numbers are generated from factors presented in an article by Finelt, S. and Crump, J.R. Predict Wastewater Generation. Hydrocarbon Processing. August 1977. p.159-166

\* = no inputs for chemical treatment

were not calculated because the respective refineries did not report wastewater flow.

#### 5.4 REFERENCES

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2. Industrial Wastewater Volatile Organic Compound Emissions--Background Information for BACT/LAER Determinations. Radian Corporation, Research Triangle Park, NC. Publication No. EPA-450/3-90-004.
3. Finelt, S. and Crump, J.R. Predict Wastewater Generation. Hydrocarbon Processing. August 1977. p. 159-166.
4. Thrash, L.A. Annual Refining Survey. Oil & Gas Journal. March 26, 1990.

## 6.0 TRANSFER

### 6.1 BACKGROUND INFORMATION

The primary source of hazardous air pollutant (HAP) emissions from transfer operations is evaporative loss during transport vessel loading.

Stored petroleum products are pumped through metered loading areas, called loading racks, and into transport vehicles such as tank trucks, railcars, and marine vessels. Loading racks contain the equipment (pumps, meters, and piping) necessary to fill delivery tank vessels with liquid products. Refineries typically utilize anywhere from 2 to 10 rack positions, depending on their throughput capacity. Each loading rack typically has from one to four loading arms, depending on the products available for loading at the rack position. Racks may service many chemicals or be dedicated to one specific chemical.<sup>1</sup>

#### 6.1.1 Emissions from Loading Losses

Loading losses occur as organic vapors in "empty" cargo vessels are displaced to the atmosphere by the liquid being loaded into the vessels. These vapors are a composite of three factors: the vapors formed in the empty vessel by evaporation of residual product from previous loads, vapors transferred to the vessel in vapor balance systems as product is unloaded, and vapors generated in the vessel as the new product is being loaded.<sup>2</sup>

The quantity of loading losses from loading operations depends on the following parameters: physical and chemical characteristics of the previous cargo, method of unloading the previous cargo, method of loading the new cargo, and the physical and chemical characteristics of the new cargo.

6.1.1.1 Product Characteristics. The emissions of each constituent present in refinery products are largely dependent on their vapor pressures. Constituents with high vapor pressures

tend to volatilize more readily. Other characteristics that contribute to emissions are concentration of the chemical in the product, molecular weight of the chemical, flow rate of the liquid stream being transferred, and the temperature and pressure of the liquid being transferred.

6.1.1.2 Methods for Loading and Unloading. Material loading may be performed using either splash, top submerged, or bottom loading methods. In splash loading, the fill pipe dispensing the cargo is lowered only partway into the cargo vessel. This method creates considerable turbulence during loading and can create high levels of vapor mist, resulting in higher emissions. If the turbulence is great enough, liquid droplets will be entrained in the vented vapors.<sup>2</sup>

A second method of loading is submerged loading. In this method, the fill pipe extends almost to the bottom of the cargo vessel. During most of submerged loading the fill pipe opening is below the liquid surface level. This substantially reduces turbulence, which in turn reduces vapors and consequently, emissions.

In bottom loading, products are loaded into the cargo vessel from the bottom of the tank. As with submerged loading, the fill pipe is below the liquid surface level most of the time, thereby reducing turbulence and vapor generation.

6.1.1.3 Recent Loading History. If a vessel has carried a nonvolatile liquid or has just been cleaned, it will contain vapor free air. If the vessel is connected to a vapor balance system or has just carried gasoline or another volatile refinery product and has not been vented, the air in the carrier vessel will contain volatile organic vapors, which are expelled during the loading operations along with newly generated vapors.<sup>2</sup>

### 6.1.2 Other Emission Sources

A major source of emissions associated with the unloading of petroleum liquids from marine vessels are ballasting operations. Ballast is water that is loaded into the marine vessel's cargo tank compartments to improve its stability during voyage. Ballasting emissions occur when the vapor space in the "empty" cargo tank is displaced to the atmosphere by ballast water being pumped into the tank. Upon arrival at the next loading port, the ballast water is pumped from the cargo tanks to a tank on shore before new cargo is loaded. The ballasting of the cargo tanks reduces the quantity of vapors returning in the empty tank, thereby reducing the quantity of vapors emitted during the subsequent tanker loading.<sup>2</sup>

## 6.2 METHOD FOR DEVELOPING HAZARDOUS AIR POLLUTANT EMISSION AND THROUGHPUT FACTORS FOR TRANSFER OPERATIONS

Transfer factors relating emissions to refinery capacity were developed by compiling information from the California refinery database. Correlations between the speciated hazardous air pollutant (HAP) emissions and throughput per transport mode, as well as between throughput per transport mode and crude charge capacity, were generated.

### 6.2.1 California Refinery Transfer Database

Ideally, emissions from transfer operations would be based on the composition and characteristics of the streams flowing into the transport vessel, the method of loading, the capacity transferred, the number of loading arms and loading racks, and the AP-42 transfer equations. However, the data necessary for this type of calculation were not available.

An alternative method for estimating emissions was developed based on the average emissions of HAP's reported by California refineries complying with the Air Toxics "Hot Spots" Information and Assessment Act of 1987 (AB 2588). For this approach, the

minimum information necessary for calculating emissions from transfer operations was:

- throughput for each transport mode;
- specific HAP emissions from each transport mode; and
- crude charge capacity of each refinery.

Information from only five refineries met these criteria. These refineries' reported annual throughputs per emission source are presented in Table 6-1. Table 6-2 presents the HAP emissions from all the reporting California refineries. Several refineries were not included in developing HAP emission and throughput factors because of lack of throughput data.

#### 6.2.2 Development of Emission Factors

Two factors were developed to characterize the transfer database: the HAP emission factor, and the throughput factor. Both are based solely on data reported from the California refineries.

6.2.2.1 Hazardous Air Pollutant Emission Factor. The HAP emission factor was generated by dividing the specific HAP emissions reported by each refinery for each transport mode by the throughput entering the transport mode. Average HAP factors were calculated from the refineries reporting applicable HAP data. Table 6-3 presents the average HAP emission factors (in lb/yr/ $10^6$  gallons of throughput).

6.2.2.2 Throughput Factor. The throughput factor was developed by dividing the throughput entering each transport mode by the crude charge capacity in each refinery. Average throughput factors were calculated from the refineries reporting applicable throughput data. Table 6-4 presents the annual average throughput factors (in  $10^3$  gal/yr/bbl/sday) for each transport mode. The crude charge capacities were taken from the Oil and Gas Journal.<sup>3</sup> The throughputs were supplied from the California Refinery Database.

### 6.3 DATABASE LIMITATIONS

The transfer database has several significant gaps. Gasoline was not reported as being transported by railcar, and only one refinery reported the transportation of C3's, jet fuel, toluene, and xylene. Therefore, these data may not be representative of transfer mechanisms of refineries throughout the United States.

Sixteen HAP's were reported from all the refineries in the California refinery database; however, no more than 12 were reported by any one refinery, and several of the HAP's were reported by only one refinery.

#### 6.3.1 Hazardous Air Pollutant Emission Factor

Because of the lack of data, no HAP factors were developed for C4 loading in any of the transfer modes. Hazardous air pollutant emission factors for railcar loading were limited to one pollutant (1,3-butadiene) for one refinery product (C3's). Emission factors for six refinery products were generated for tank truck loading. However, three of the products have an emission factor for only one pollutant, and two have factors for only two pollutants.

#### 6.3.2 Throughput Factor

Tank truck loading contains the most complete throughput factors. Only three refinery products (gasoline, diesel, and jet fuel) have factors for marine loading, and only C4's and C3's have a throughput factor for railcar loading.

#### 6.4 REFERENCES

1. Evaluation of Air Pollution Regulatory Strategies for Gasoline Marketing Industry. Office of Air Quality Planning and Standards. U.S. Environmental Protection Agency. Washington, D.C. EPA-450/3-84-012a. July 1984.
2. Compilation of Air Pollutant Emission Factors. Volume 1: Stationary Point and Area Sources. AP-42. Fourth Edition. U.S. Environmental Protection Agency. Office of Air Quality Planning and Standards. September 1985.
3. Thrash, L.A. Annual Refining Survey. Oil and Gas Journal. March 26, 1990.

TABLE 6-1. ANNUAL THROUGHPUTS PER TRANSFER MODE (10<sup>3</sup> gal/yr)

| Refinery | Crude charge capacity (bbls/sd) | Material transferred  | Transfer Mode   |   |                           |
|----------|---------------------------------|---|-----------------|---|---------------------------|
|          |                                 |   | Railcar loading | Tank truck loading                                  | Marine loading            |
| A        | 132,000                         | Gasoline  |                 |   | Confidential              |
| F        | 121,400                         | Gasoline  |                 |   | 176,000                   |
| G        | 55,000                          | Gasoline<br>C4's<br>Diesel  | 11,500          |   | 15,400<br>509,000         |
| I        | 145,000                         | Gasoline<br>Diesel<br>C3's<br>C4's<br>Jet fuel<br>Toluene<br>Xylene | 367<br>31       | 116,000<br>10,400<br>887<br>1,470<br>1,450<br>1,040 | 8,570<br>355,000<br>6,170 |
| J        | 143,000                         | Gasoline  |                 | Confidential  | Confidential              |

Note: A blank entry indicates no data were reported.

TABLE 6-2. HAZARDOUS AIR POLLUTANT EMISSIONS FROM CALIFORNIA REFINERIES (lb/yr)

| Material processed | HAP                 | Railcar loading | Tank truck loading | Marine loading | Bulk          |           |
|--------------------|---------------------|-----------------|--------------------|----------------|---------------|-----------|
|                    |                     |                 |                    |                | loading-total | emissions |
| <u>Refinery A</u>  |                     |                 |                    |                |               |           |
| Gasoline           | Benzene             |                 |                    | 1,890          | 1,890         |           |
|                    | Ethylene dichloride |                 |                    | 32.2           | 32.2          |           |
|                    | Ethylene dibromide  |                 |                    | 1.3            | 1.3           |           |
| <u>Refinery B*</u> |                     |                 |                    |                |               |           |
| No Data            | Benzene             |                 |                    |                | 1,080         |           |
|                    | Naphthalene         |                 |                    |                | 2.6           |           |
|                    | Toluene             |                 |                    |                | 1,950         |           |
|                    | Xylenes             |                 |                    |                | 447           |           |
| <u>Refinery C*</u> |                     |                 |                    |                |               |           |
| No Data            | No data             |                 |                    |                |               |           |
| <u>Refinery D*</u> |                     |                 |                    |                |               |           |
| Crude              | Benzene             |                 |                    |                |               | 13        |
|                    | Chlorobenzene       |                 |                    |                |               | 1.25      |
|                    | Chloroform          |                 |                    |                |               | 24.6      |
|                    | Cresol              |                 |                    |                |               | 0.007     |
|                    | 1,4-Dioxane         |                 |                    |                |               | 93        |
|                    | Ethylene dichloride |                 |                    |                |               | 10.2      |

(continued)

TABLE 6-2. (Continued)

| Material processed            | HAP                 | Railcar loading | Tank truck loading | Marine loading | Bulk loading-total emissions |
|-------------------------------|---------------------|-----------------|--------------------|----------------|------------------------------|
| <u>Refinery D*, Continued</u> |                     |                 |                    |                |                              |
|                               | Ethylene dibromide  |                 |                    |                | 1.73                         |
|                               | Naphthalene         |                 |                    |                | 0.013                        |
|                               | Phenol              |                 |                    |                | 0.014                        |
|                               | Styrene             |                 |                    |                | 0.65                         |
|                               | Toluene             |                 |                    |                | 14.43                        |
|                               | Xylenes             |                 |                    |                | 6.13                         |
|                               |                     |                 |                    |                |                              |
| Naphtha                       | Benzene             |                 |                    |                | 27.2                         |
|                               | Chlorobenzene       |                 |                    |                | 2.62                         |
|                               | Chloroform          |                 |                    |                | 51.4                         |
|                               | Cresol              |                 |                    |                | 0.013                        |
|                               | 1,4-Dioxane         |                 |                    |                | 194                          |
|                               | Ethylene dichloride |                 |                    |                | 21.4                         |
|                               | Ethylene dibromide  |                 |                    |                | 3.61                         |
|                               | Naphthalene         |                 |                    |                | 0.045                        |
|                               | Phenol              |                 |                    |                | 0.027                        |
|                               | Styrene             |                 |                    |                | 1.36                         |
|                               | Toluene             |                 |                    |                | 25.9                         |
|                               | Xylenes             |                 |                    |                | 12.3                         |
|                               |                     |                 |                    |                |                              |
| Kerosene                      | Benzene             |                 |                    |                | 0.04                         |
|                               | Chlorobenzene       |                 |                    |                | 0.004                        |
|                               | Chloroform          |                 |                    |                | 0.087                        |
|                               | 1,4-Dioxane         |                 |                    |                | 0.317                        |
|                               | Ethylene dichloride |                 |                    |                | 0.036                        |
|                               | Ethylene dibromide  |                 |                    |                | 0.006                        |

(continued)

TABLE 6-2. (Continued)

| Material processed            | HAP                 | Railcar loading | Tank truck loading | Marine loading | Bulk loading-total emissions |
|-------------------------------|---------------------|-----------------|--------------------|----------------|------------------------------|
| <u>Refinery D*, Continued</u> |                     |                 |                    |                |                              |
| Styrene                       |                     |                 |                    |                | 0.002                        |
| Toluene                       |                     |                 |                    |                | 0.028                        |
| Xylenes                       |                     |                 |                    |                | 0.027                        |
| <u>Refinery E*</u>            |                     |                 |                    |                |                              |
| No Data                       | No data             |                 |                    |                |                              |
| <u>Refinery F</u>             |                     |                 |                    |                |                              |
| Gasoline                      | Benzene             |                 |                    | 4,590          | 4,590                        |
|                               | Ethylene dichloride |                 |                    | 9              | 9                            |
|                               | Ethylene dibromide  |                 |                    | 0.3            | 0.3                          |
| <u>Refinery G</u>             |                     |                 |                    |                |                              |
| Gasoline                      | Benzene             |                 |                    | 68             | 68                           |
|                               | Toluene             |                 |                    | 57             | 57                           |
|                               | Xylenes             |                 |                    | 11.7           | 11.7                         |
| Diesel Fuel                   | Naphthalene         |                 |                    | 0.27           | 0.27                         |
|                               | Toluene             |                 |                    | 0.44           | 0.44                         |
|                               | Xylenes             |                 |                    | 0.2            | 0.2                          |
| (continued)                   |                     |                 |                    |                |                              |

TABLE 6-2. (Continued)

| Material processed | HAP           | Railcar loading | Tank truck loading | Marine loading | Bulk loading-total emissions |
|--------------------|---------------|-----------------|--------------------|----------------|------------------------------|
| <u>Refinery H*</u> |               |                 |                    |                |                              |
| Gasoline           | Benzene       |                 |                    |                | 0.148                        |
|                    | Toluene       |                 |                    |                | 0.37                         |
|                    | Xylenes       |                 |                    |                | 0.23                         |
| <u>Refinery I</u>  |               |                 |                    |                |                              |
| Gasoline           | Benzene       |                 |                    | 506            | 506                          |
|                    | Toluene       |                 |                    | 156            | 156                          |
|                    | Xylenes       |                 |                    | 7.99           | 7.99                         |
| Diesel             | Toluene       |                 | 0.0944             | 4.99           | 5.08                         |
|                    | Xylenes       |                 | 0.223              | 11.8           | 12.0                         |
| Jet Fuel           | Toluene       |                 | 0.00164            | 0.113          | 0.114                        |
|                    | Xylenes       |                 | 0.00664            | 0.455          | 0.462                        |
| C3's               | 1,3-Butadiene | 0.0031          | 0.146              |                | 0.149                        |
| Toluene            | Toluene       |                 | 20.8               |                | 20.8                         |
| Xylene             | Xylenes       |                 | 6.96               |                | 6.96                         |

(continued)

TABLE 6-2. (Continued)

| Material processed | HAP                 | Railcar loading | Tank truck loading | Marine loading | Bulk loading-total emissions |
|--------------------|---------------------|-----------------|--------------------|----------------|------------------------------|
| <u>Refinery J</u>  |                     |                 |                    |                |                              |
| Gasoline           | Benzene             |                 | 430                | 214            | 664                          |
|                    | Ethylene dichloride |                 | 7.30               |                | 7.30                         |
|                    | Ethylene dibromide  |                 | 0.3                |                | 0.3                          |
|                    | Toluene             |                 | 31                 | 190            | 221                          |
|                    | Xylenes             |                 | 13                 | 75             | 88                           |
| <u>Refinery K*</u> |                     |                 |                    |                |                              |
| Gasoline           | Benzene             |                 |                    |                | 2.33                         |
|                    | Cresols             |                 |                    |                | 0.22                         |
|                    | Naphthalene         |                 |                    |                | 2.62                         |
|                    | Phenol              |                 |                    |                | .025                         |
|                    | Toluene             |                 |                    |                | 12.21                        |
|                    | Xylenes             |                 |                    |                | 15.95                        |

Note: A blank entry indicates no data were reported.

\*Data not used for HAP's factor development as emissions not reported by transfer mode.

TABLE 6-3. HAZARDOUS AIR POLLUTANT EMISSION FACTOR, BY MATERIAL TRANSFERRED  
(lb/10<sup>6</sup> gallons throughput)

| Emission source    | Pollutant           | Gasoline | Diesel  | C3's    | C4's | Jet     | Toluene | Xylene |
|--------------------|---------------------|----------|---------|---------|------|---------|---------|--------|
| Railcar Loading    | 1,3-Butadiene       |          |         | 0.00844 |      |         |         |        |
| Tank Truck Loading | Benzene             | 1.31     |         |         |      |         |         |        |
|                    | Ethylene dichloride | 0.0223   |         |         |      |         |         |        |
|                    | Ethylene dibromide  | 0.00091  |         |         |      |         |         |        |
|                    | Toluene             | 0.0948   | 0.00081 |         |      | 0.00112 | 14.4    |        |
|                    | Xylenes             | 0.04     | 0.00192 |         |      | 0.00452 |         | 6.67   |
|                    | 1,3-Butadiene       |          |         | 0.014   |      |         |         |        |
| Marine Loading     | Benzene             | 23.4     |         |         |      |         |         |        |
|                    | Ethylene dichloride | 0.255    |         |         |      |         |         |        |
|                    | Ethylene dibromide  | 0.01     |         |         |      |         |         |        |
|                    | Naphthalene         |          | 0.00053 |         |      |         |         |        |
|                    | Toluene             | 7.50     | 0.00746 |         |      | 0.018   |         |        |
|                    | Xylenes             | 0.644    | 0.0168  |         |      | 0.0737  |         |        |

Note: A blank entry indicates throughputs or HAP emissions were not reported.

TABLE 6-4. ANNUAL THROUGHPUT FACTOR  
(10<sup>3</sup> gal/yr/bbl/sday crude charge)

| Material processed | Railcar loading | Tank truck loading | Marine loading |
|--------------------|-----------------|--------------------|----------------|
| Gasoline           |                 | 2.29               | .905           |
| Diesel             |                 | .8                 | 5.85           |
| C3's               | .0025           | 0.0717             |                |
| C4's               | .105            | 0.0061             |                |
| Jet Fuel           |                 | 0.01               | 0.0426         |
| Toluene            |                 | 0.0099             |                |
| Xylene             |                 | 0.0072             |                |

Note: A blank entry indicates throughputs were not reported.

## 7.0 TOXIC CHEMICAL RELEASE INVENTORY SYSTEM DATABASE

### 7.1 DESCRIPTION OF TOXIC CHEMICAL RELEASE INVENTORY SYSTEM DATABASE

The Toxic Chemical Release Inventory System (TRIS) database is comprised of information gathered from U. S. Environmental Protection Agency (EPA) Form R, the Toxic Chemical Release Inventory Reporting Form. Section 313 Title III of the Superfund Amendments and Reauthorization Act (SARA) requires every refiner to submit EPA Form R for each of its refining facilities. The EPA Form R consists of four parts:

- facility identification information;
- off-site locations to which wastes with chemicals are transferred;
- chemical-specific information including chemical identity, uses of the chemical in the facility, waste treatment methods and their efficiencies, releases of chemicals to the environment on site, and transfers of the chemical in wastes to off-site locations; and
- supplemental information including additional information on releases of chemicals to the environment on-site, transfers of the chemicals in waste off-site, and waste treatment methods and efficiencies.

The TRIS database is comprised of over 300 chemicals/compounds listed in SARA Title III. However, only 153 of the 190 hazardous air pollutants (HAP's) listed in the 1990 Clean Air Act Amendments are included on the SARA Title III list.

### 7.2 ANALYSIS OF DATA FROM TOXIC CHEMICAL RELEASE INVENTORY SYSTEM

Radian Corporation accessed the EPA's 1989 TRIS database and tabulated reported emissions from petroleum refineries for the 153 HAP's in TRIS. Air releases are divided into just two categories: fugitive and point. Fugitive emissions include releases from source types such as equipment leaks and wastewater

operations. Point emissions include releases from source types such as process vents, storage tanks, and transfer operations. Only 66 of the 153 HAP's were reported as being released from refineries. The database includes 202 refineries from the United States, Puerto Rico, and the Virgin Islands. The emissions data from these refineries are summarized in Tables 7-1 and 7-2.

Table 7-1 ranks the HAP's by the number of facilities reporting releases of each chemical. Total emissions from point sources, fugitive sources, and total air releases (point plus fugitive) are calculated to be 6,936 tons per year (tpy), 12,326 tpy, and 19,262 tpy, respectively. Only 5 chemicals (benzene, toluene, xylenes, ethyl-benzene, and chlorine) are reported by over 100 refineries. These 5 chemicals account for 63.9 percent of the reported emissions by mass of the total air releases. The 10 most commonly reported chemicals account for 71.7 percent of total emissions. Benzene is the most frequently reported HAP, with 184 out of 202 refineries reporting emissions. Benzene constitutes 14.3 percent of the releases.

Table 7-2 ranks each HAP according to total air releases. The top 5 chemicals (toluene, xylenes, benzene, methyl ethyl ketone, and ethyl-benzene), ranked in terms of mass releases, account for 75.2 percent of the total air releases and the top 10 chemicals account for 88 percent. Toluene has the largest emissions, with air releases totalling 5,428 tpy for 182 refineries. It constitutes 28.2 percent of the total air releases.

The average number of chemicals reported for each refinery is six. However; the number of chemicals ranges from as many as 25 to as few as 1.

TABLE 7-1. 1989 PETROLEUM REFINERY TRIS DATABASE EMISSIONS, RANKED BY FREQUENCY OF CHEMICALS BEING REPORTED

| CAS number | Chemical                                     | Number of refineries | Point releases (tons/yr) | Fugitive releases (tons/yr) | Total air releases (tons/yr) | Average releases per facility | Total releases (wt %) | Releases (cum. wt %) |
|------------|--|----------------------|--------------------------|-----------------------------|------------------------------|-------------------------------|-----------------------|----------------------|
| 71432      | Benzene (including benzene from gasoline)    | 184                  | 1327                     | 1424                        | 2751                         | 15.0                          | 14.3                  | 14.3                 |
| 108883     | Toluene                                      | 182                  | 1983                     | 3444                        | 5428                         | 29.8                          | 28.2                  | 42.5                 |
| 1330207    | Xylenes (isomers and mixtures)               | 166                  | 1000                     | 2174                        | 3175                         | 19.1                          | 16.5                  | 58.9                 |
| 100414     | Ethyl-benzene                                | 154                  | 279                      | 519                         | 798                          | 5.18                          | 4.14                  | 63.1                 |
| 7782505    | Chlorine                                     | 115                  | 94.0                     | 56.5                        | 151                          | 1.31                          | 0.781                 | 63.9                 |
| 91203      | Naphthalene                                  | 89                   | 49.3                     | 152                         | 201                          | 2.26                          | 1.04                  | 64.9                 |
| 99999909   | Lead compounds                               | 85                   | 1.43                     | 4.34                        | 5.78                         | 0.068                         | 0.0300                | 64.9                 |
| 1634044    | Methyl tert butyl ether                      | 64                   | 653                      | 140                         | 793                          | 12.4                          | 4.12                  | 69.1                 |
| 106990     | 1,3-Butadiene                                | 63                   | 32.6                     | 123                         | 155                          | 2.46                          | 0.806                 | 69.9                 |
| 108952     | Phenol                                       | 63                   | 186                      | 171                         | 357                          | 5.66                          | 1.85                  | 71.7                 |
| 99999907   | Chromium compounds                           | 61                   | 63.1                     | 39.8                        | 103                          | 1.69                          | 0.534                 | 72.3                 |
| 7664393    | Hydrogen fluoride (hydrofluoric acid)        | 61                   | 151                      | 116                         | 267                          | 4.38                          | 1.39                  | 73.6                 |
| 67561      | Methanol                                     | 61                   | 26.1                     | 265                         | 292                          | 4.78                          | 1.51                  | 75.2                 |
| 111422     | Diethanolamine                               | 60                   | 0.36                     | 28.2                        | 28.6                         | 0.476                         | 0.148                 | 75.3                 |
| 98828      | Cumene                                       | 50                   | 290                      | 348                         | 638                          | 12.8                          | 3.31                  | 78.6                 |
| 99999916   | Nickel compounds                             | 50                   | 8.83                     | 1.16                        | 9.98                         | 0.200                         | 0.0518                | 78.7                 |
| 7647010    | Hydrochloric acid                            | 37                   | 94.2                     | 24.6                        | 119                          | 3.21                          | 0.617                 | 79.3                 |
| 71556      | Methyl chloroform (1,1,1-trichloroethane)    | 35                   | 0.250                    | 123                         | 123                          | 3.52                          | 0.640                 | 79.9                 |
| 107211     | Ethylene glycol                              | 33                   | 31.1                     | 7.91                        | 39.0                         | 1.18                          | 0.203                 | 80.1                 |
| 99999915   | Manganese compounds                          | 29                   | 2.46                     | 0.63                        | 3.09                         | 0.107                         | 0.016                 | 80.1                 |
| 107062     | Ethylene dichloride (1,2-dichloroethane)     | 28                   | 0.54                     | 4.85                        | 5.39                         | 0.192                         | 0.028                 | 80.2                 |
| 106934     | Ethylene dibromide (dibromoethane)           | 27                   | 0.54                     | 1.39                        | 1.93                         | 0.071                         | 0.010                 | 80.2                 |
| 78933      | Methyl ethyl ketone (2-butanone)             | 27                   | 119                      | 2216                        | 2335                         | 86.5                          | 12.1                  | 92.3                 |
| 56235      | Carbon tetrachloride                         | 26                   | 0.16                     | 11.9                        | 12.0                         | 0.463                         | 0.0625                | 92.4                 |
| 99999913   | Cobalt compounds                             | 26                   | 0.06                     | 0.63                        | 0.68                         | 0.026                         | 0.00353               | 92.4                 |
| 1319773    | Cresols/cresylic acid (isomers and mixture)  | 24                   | 2.82                     | 17.7                        | 20.5                         | 0.854                         | 0.106                 | 92.5                 |
| 95476      | Xylenes (isomers and mixture)                | 21                   | 74.4                     | 130                         | 205                          | 9.74                          | 1.06                  | 93.5                 |
| 106423     | Xylenes (isomers and mixture)                | 18                   | 155                      | 233                         | 388                          | 21.6                          | 2.01                  | 95.6                 |
| 108383     | Xylenes (isomers and mixture)                | 17                   | 59.0                     | 164                         | 223                          | 13.1                          | 1.16                  | 96.7                 |
| 99999903   | Glycol ethers                                | 12                   | 0.31                     | 26.1                        | 26.4                         | 2.2                           | 0.137                 | 96.8                 |
| 100425     | Styrene                                      | 12                   | 7.99                     | 6.87                        | 14.9                         | 1.24                          | 0.0771                | 96.9                 |
| 92524      | Biphenyl                                     | 11                   | 0.99                     | 11.4                        | 12.4                         | 1.13                          | 0.0644                | 97.0                 |
| 1332214    | Asbestos                                     | 9                    | 0                        | 0.88                        | 0.88                         | 0.098                         | 0.00457               | 97.0                 |
| 75150      | Carbon disulfide                             | 6                    | 32.0                     | 1.22                        | 33.2                         | 5.54                          | 0.173                 | 97.2                 |
| 50000      | Formaldehyde                                 | 6                    | 13.4                     | 5.63                        | 19                           | 3.17                          | 0.0986                | 97.3                 |
| 99999911   | Antimony compounds                           | 5                    | 0.93                     | 0                           | 0.93                         | 0.186                         | 0.00483               | 97.3                 |
| 99999904   | Arsenic compounds (inorganic includ. arsine) | 5                    | 0                        | 0                           | 0                            | 0                             | 0                     | 97.3                 |
| 108101     | Methyl isobutyl ketone (hexanone)            | 5                    | 32.3                     | 172                         | 204                          | 40.8                          | 1.06                  | 98.3                 |
| 99999906   | Cadmium compounds                            | 4                    | 0                        | 0                           | 0                            | 0                             | 0                     | 98.3                 |
| 302012     | Hydrazine                                    | 4                    | 0.21                     | 0.25                        | 0.46                         | 0.115                         | 0.00239               | 98.3                 |
| 78875      | Propylene dichloride (1,2-dichloropropane)   | 4                    | 0.38                     | 1.37                        | 1.75                         | 0.438                         | 0.00909               | 98.3                 |
| 99999914   | Cyanide compounds                            | 3                    | 0.05                     | 0                           | 0.05                         | 0.017                         | 0.000260              | 98.3                 |
| 1336363    | Polychlorinated biphenyls (aroclor)          | 3                    | 0                        | 0                           | 0                            | 0                             | 0                     | 98.3                 |
| 542756     | 1,3-Dichloropropane                          | 2                    | 1.13                     | 2.38                        | 3.5                          | 1.75                          | 0.0182                | 98.4                 |
| 75058      | Acetonitrile                                 | 2                    | 4.49                     | 59.2                        | 63.7                         | 31.8                          | 0.330                 | 98.7                 |

(continued)

TABLE 7-1. (Continued)

| CAS number | Chemical                                    | Number of refineries | Point releases (tons/yr) | Fugitive releases (tons/yr) | Total air releases (tons/yr) | Average releases per facility | Total releases (wt %) | Releases (cum.wt %) |
|------------|---|----------------------|--------------------------|-----------------------------|------------------------------|-------------------------------|-----------------------|---------------------|
| 107051     | Allyl chloride                              | 2                    | 27.5                     | 27.3                        | 54.7                         | 27.4                          | 0.284                 | 99                  |
| 463581     | Carbonyl sulfide                            | 2                    | 90                       | 0                           | 90                           | 45                            | 0.467                 | 99.4                |
| 106898     | Epichlorohydrin (1-chloro-2,3-epoxypropane) | 2                    | 28.3                     | 59.5                        | 87.8                         | 43.9                          | 0.456                 | 99.9                |
| 99999910   | Mercury compounds                           | 2                    | 0.05                     | 0                           | 0.05                         | 0.025                         | 0.00026               | 100                 |
| 99999917   | Selenium compounds                          | 2                    | 0                        | 0                           | 0                            | 0                             | 0                     | 100                 |
| 79016      | Trichloroethylene                           | 2                    | 0.01                     | 1.25                        | 1.26                         | 0.63                          | 0.00654               | 100                 |
| 106887     | 1,2-Epoxybutane                             | 1                    | 0                        | 0.04                        | 0.04                         | 0.04                          | 0.000208              | 100                 |
| 123911     | 1,4-Dioxane(1,4-diethyleneoxide)            | 1                    | 0                        | 0.01                        | 0.01                         | 0.01                          | 0.000052              | 100                 |
| 584849     | 2,4-Toluene diisocyanate                    | 1                    | 0                        | 0                           | 0                            | 0                             | 0                     | 100                 |
| 79107      | Acrylic acid                                | 1                    | 0                        | 0.14                        | 0.14                         | 0.14                          | 0.000727              | 100                 |
| 99999905   | Beryllium compounds                         | 1                    | 0                        | 0                           | 0                            | 0                             | 0                     | 100                 |
| 67663      | Chloroform                                  | 1                    | 0                        | 0.04                        | 0.04                         | 0.04                          | 0.000208              | 100                 |
| 140885     | Ethyl acrylate                              | 1                    | 0.08                     | 0                           | 0.08                         | 0.08                          | 0.000415              | 100                 |
| 75218      | Ethylene oxide                              | 1                    | 9.5                      | 6.5                         | 16                           | 16                            | 0.0831                | 100                 |
| 108316     | Maleic anhydride                            | 1                    | 0.13                     | 0.13                        | 0.25                         | 0.25                          | 0.00130               | 100                 |
| 74873      | Methyl chloride (chloromethane)             | 1                    | 0                        | 1.55                        | 1.55                         | 1.55                          | 0.00805               | 100                 |
| 80626      | Methyl methacrylate                         | 1                    | 0.13                     | 0.13                        | 0.25                         | 0.25                          | 0.00130               | 100                 |
| 75092      | Methylene chloride                          | 1                    | 0                        | 0.13                        | 0.13                         | 0.13                          | 0.00067               | 100                 |
| 127184     | Tetrachloroethylene (perchloroethylene)     | 1                    | 0.08                     | 0.27                        | 0.35                         | 0.35                          | 0.00182               | 100                 |
| 7550450    | Titanium tetrachloride                      | 1                    | 0                        | 0                           | 0                            | 0                             | 0                     | 100                 |
| 108054     | Vinyl acetate                               | 1                    | 0.13                     | 0.13                        | 0.25                         | 0.25                          | 0.00130               | 100                 |
| Total      |   |                      | 6936                     | 12326                       | 19262                        |                               |                       |                     |

TABLE 7-2. 1989 PETROLEUM REFINERY TRIS DATABASE EMISSIONS, RANKED BY TOTAL EMISSIONS

| CAS number | Chemical                                    | Number of refineries | Point releases (tons/yr) | Fugitive releases (tons/yr) | Total air releases (tons/yr) | Average releases per facility | Total releases (wt %) | Releases (cum.wt %) |
|------------|---|----------------------|--------------------------|-----------------------------|------------------------------|-------------------------------|-----------------------|---------------------|
| 108883     | Toluene                                     | 182                  | 1983                     | 3444                        | 5428                         | 29.8                          | 28.2                  | 28.2                |
| 1330207    | Xylenes (isomers and mixtures)              | 166                  | 1000                     | 2174                        | 3175                         | 19.1                          | 16.5                  | 44.7                |
| 71432      | Benzene (including benzene from gasoline)   | 184                  | 1327                     | 1424                        | 2751                         | 15.0                          | 14.3                  | 14.3                |
| 78933      | Methyl ethyl ketone (2-butanone)            | 27                   | 119                      | 2216                        | 2335                         | 86.5                          | 12.1                  | 26.4                |
| 100414     | Ethyl-benzene                               | 154                  | 279                      | 519                         | 798                          | 5.18                          | 4.14                  | 30.5                |
| 1634044    | Methyl tert butyl ether                     | 64                   | 653                      | 140                         | 793                          | 12.4                          | 4.12                  | 34.7                |
| 98828      | Cumene                                      | 50                   | 290                      | 348                         | 638                          | 12.8                          | 3.31                  | 38.0                |
| 106423     | Xylenes (isomers and mixture)               | 18                   | 155                      | 233                         | 388                          | 21.6                          | 2.01                  | 40.0                |
| 108952     | Phenol                                      | 63                   | 186                      | 171                         | 357                          | 5.66                          | 1.85                  | 41.8                |
| 67561      | Methanol                                    | 61                   | 26.1                     | 265                         | 292                          | 4.78                          | 1.51                  | 43.4                |
| 7664393    | Hydrogen fluoride (hydrofluoric acid)       | 61                   | 151                      | 116                         | 267                          | 4.38                          | 1.39                  | 44.7                |
| 108383     | Xylenes (isomers and mixture)               | 17                   | 59.0                     | 164                         | 223                          | 13.1                          | 1.16                  | 45.9                |
| 95476      | Xylenes (isomers and mixture)               | 21                   | 74.4                     | 130                         | 205                          | 9.74                          | 1.06                  | 47.0                |
| 108101     | Methyl isobutyl ketone (hexanone)           | 5                    | 32.3                     | 172                         | 204                          | 40.8                          | 1.06                  | 48.0                |
| 91203      | Naphthalene                                 | 89                   | 49.3                     | 152                         | 201                          | 2.26                          | 1.04                  | 49.1                |
| 106990     | 1,3-Butadiene                               | 63                   | 32.6                     | 123                         | 155                          | 2.46                          | 0.806                 | 49.9                |
| 7782505    | Chlorine                                    | 115                  | 94.0                     | 56.5                        | 151                          | 1.31                          | 0.781                 | 50.7                |
| 71556      | Methyl chloroform (1,1,1-trichloroethane)   | 35                   | 0.250                    | 123                         | 123                          | 3.52                          | 0.640                 | 51.3                |
| 7647010    | Hydrochloric acid                           | 37                   | 94.2                     | 24.6                        | 119                          | 3.21                          | 0.617                 | 51.9                |
| 99999907   | Chromium compounds                          | 61                   | 63.1                     | 39.8                        | 103                          | 1.69                          | 0.534                 | 52.4                |
| 463581     | Carbonyl sulfide                            | 2                    | 90                       | 0                           | 90                           | 45                            | 0.467                 | 99.4                |
| 106898     | Epichlorohydrin (1-chloro-2,3-epoxypropane) | 2                    | 28.3                     | 59.5                        | 87.8                         | 43.9                          | 0.456                 | 99.9                |
| 75058      | Acetonitrile                                | 2                    | 4.49                     | 59.2                        | 63.7                         | 31.8                          | 0.330                 | 100.2               |
| 107051     | Allyl chloride                              | 33                   | 31.1                     | 7.91                        | 39.0                         | 27.4                          | 0.284                 | 99                  |
| 107211     | Ethylene glycol                             | 6                    | 32.0                     | 1.22                        | 33.2                         | 1.18                          | 0.203                 | 99.2                |
| 75150      | Carbon disulfide                            | 60                   | 0.36                     | 28.2                        | 28.6                         | 5.54                          | 0.173                 | 99.4                |
| 111422     | Diethanolamine                              | 12                   | 0.31                     | 26.1                        | 26.4                         | 0.476                         | 0.148                 | 99.5                |
| 99999903   | Glycol ethers                               | 24                   | 2.82                     | 17.7                        | 20.5                         | 2.2                           | 0.137                 | 99.7                |
| 1319773    | Cresols/cresylic acid (isomers and mixture) | 6                    | 13.4                     | 5.63                        | 19                           | 0.854                         | 0.106                 | 99.8                |
| 50000      | Formaldehyde                                | 1                    | 9.5                      | 6.5                         | 16                           | 3.17                          | 0.0986                | 99.9                |
| 75218      | Ethylene oxide                              | 12                   | 7.99                     | 6.87                        | 14.9                         | 16                            | 0.0831                | 100                 |
| 100425     | Styrene                                     | 11                   | 0.99                     | 11.4                        | 12.4                         | 1.24                          | 0.0771                | 100.0               |
| 92524      | Biphenyl                                    | 26                   | 0.16                     | 11.9                        | 12.0                         | 1.13                          | 0.0644                | 100.1               |
| 56235      | Carbon tetrachloride                        | 50                   | 8.83                     | 1.16                        | 9.98                         | 0.463                         | 0.0625                | 100.2               |
| 99999916   | Nickel compounds                            | 85                   | 1.43                     | 4.34                        | 5.78                         | 0.200                         | 0.0518                | 100.2               |
| 99999909   | Lead compounds                              | 28                   | 0.54                     | 4.85                        | 5.39                         | 0.068                         | 0.0300                | 100.2               |
| 107062     | Ethylene dichloride (1,2-dichloroethane)    | 2                    | 1.13                     | 2.38                        | 3.5                          | 0.192                         | 0.028                 | 100.3               |
| 542756     | 1,3-dichloropropene                         | 29                   | 2.46                     | 0.63                        | 3.09                         | 1.75                          | 0.0182                | 100.3               |
| 99999915   | Manganese compounds                         | 27                   | 0.54                     | 1.39                        | 1.93                         | 0.107                         | 0.016                 | 100.3               |
| 106934     | Ethylene dibromide (dibromoethane)          | 4                    | 0.38                     | 1.37                        | 1.75                         | 0.071                         | 0.010                 | 100.3               |
| 78875      | Propylene dichloride (1,2-dichloropropane)  | 1                    | 0                        | 1.55                        | 1.55                         | 0.438                         | 0.00909               | 100.3               |
| 74873      | Methyl chloride (chloromethane)             | 2                    | 0.01                     | 1.25                        | 1.26                         | 1.55                          | 0.00805               | 100                 |
| 79016      | Trichloroethylene                           | 5                    | 0.93                     | 0                           | 0.93                         | 0.63                          | 0.00654               | 100                 |
| 99999911   | Antimony compounds                          | 9                    | 0                        | 0.88                        | 0.88                         | 0.186                         | 0.00483               | 100.3               |
| 1332214    | Asbestos                                    |                      | 0                        |                             | 0.88                         | 0.098                         | 0.00457               | 100.3               |

(continued)

TABLE 7-2. (Continued)

| CAS number | Chemical                                     | Number of refineries | Point releases (tons/yr) | Fugitive releases (tons/yr) | Total air releases (tons/yr) | Average releases per facility | Total releases (wt %) | Releases (cum. wt %) |
|------------|--|----------------------|--------------------------|-----------------------------|------------------------------|-------------------------------|-----------------------|----------------------|
| 99999913   | Cobalt compounds                             | 26                   | 0.06                     | 0.63                        | 0.68                         | 0.026                         | 0.00353               | 100.3                |
| 302012     | Hydrazine                                    | 4                    | 0.21                     | 0.25                        | 0.46                         | 0.115                         | 0.00239               | 100.3                |
| 127184     | Tetrachloroethylene (perchloroethylene)      | 1                    | 0.08                     | 0.27                        | 0.35                         | 0.35                          | 0.00182               | 100                  |
| 108316     | Maleic anhydride                             | 1                    | 0.13                     | 0.13                        | 0.25                         | 0.25                          | 0.00130               | 100                  |
| 80626      | Methyl methacrylate                          | 1                    | 0.13                     | 0.13                        | 0.25                         | 0.25                          | 0.00130               | 100                  |
| 108054     | Vinyl acetate                                | 1                    | 0.13                     | 0.13                        | 0.25                         | 0.25                          | 0.00130               | 100                  |
| 79107      | Acrylic acid                                 | 1                    | 0                        | 0.14                        | 0.14                         | 0.14                          | 0.000727              | 100                  |
| 75092      | Methylene chloride                           | 1                    | 0                        | 0.13                        | 0.13                         | 0.13                          | 0.00067               | 100                  |
| 140885     | Ethyl acrylate                               | 1                    | 0.08                     | 0                           | 0.08                         | 0.08                          | 0.000415              | 100                  |
| 99999914   | Cyanide compounds                            | 3                    | 0.05                     | 0                           | 0.05                         | 0.017                         | 0.000260              | 100.4                |
| 99999910   | Mercury compounds                            | 2                    | 0.05                     | 0                           | 0.05                         | 0.025                         | 0.00026               | 100                  |
| 106887     | 1,2-Epoxybutane                              | 1                    | 0                        | 0.04                        | 0.04                         | 0.04                          | 0.000208              | 100                  |
| 67663      | Chloroform                                   | 1                    | 0                        | 0.04                        | 0.04                         | 0.04                          | 0.000208              | 100                  |
| 123911     | 1,4-Dioxane(1,4-diethyleneoxide)             | 1                    | 0                        | 0.01                        | 0.01                         | 0.01                          | 0.000052              | 100                  |
| 584849     | 2,4-Toluene diisocyanate                     | 1                    | 0                        | 0                           | 0                            | 0                             | 0                     | 100                  |
| 99999904   | Arsenic compounds (inorganic includ. arsine) | 5                    | 0                        | 0                           | 0                            | 0                             | 0                     | 100.0                |
| 99999905   | Beryllium compounds                          | 1                    | 0                        | 0                           | 0                            | 0                             | 0                     | 100                  |
| 99999906   | Cadmium compounds                            | 4                    | 0                        | 0                           | 0                            | 0                             | 0                     | 100.0                |
| 1336363    | Polychlorinated biphenyls (aroclor)          | 3                    | 0                        | 0                           | 0                            | 0                             | 0                     | 100.0                |
| 99999917   | Selenium compounds                           | 2                    | 0                        | 0                           | 0                            | 0                             | 0                     | 100                  |
| 7550450    | Titanium tetrachloride                       | 1                    | 0                        | 0                           | 0                            | 0                             | 0                     | 100                  |
| Total      |  |                      | 6936                     | 12326                       | 19262                        |                               |                       |                      |